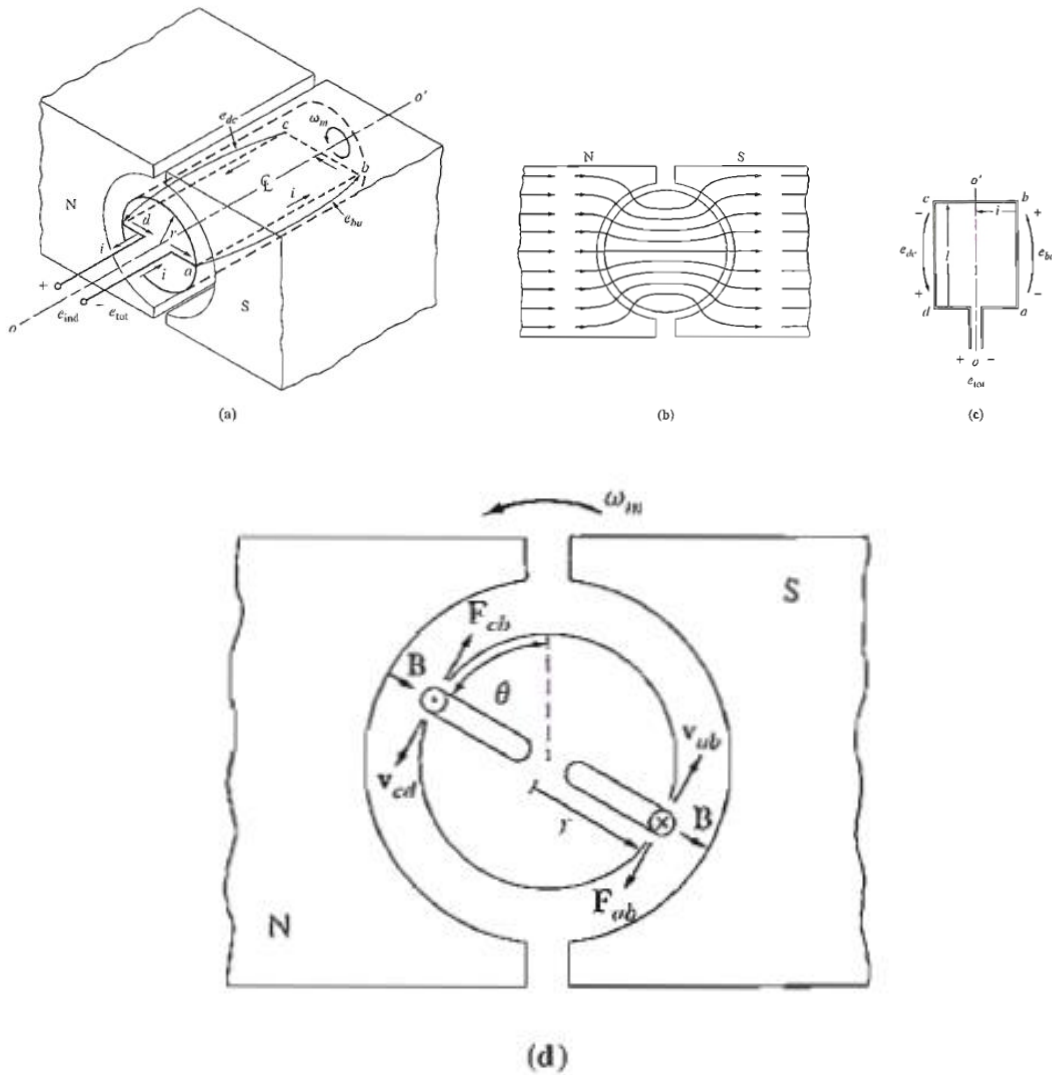


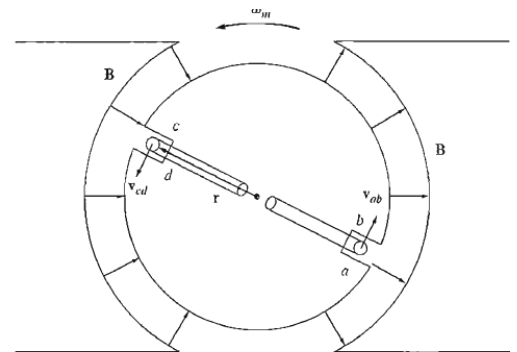
Study Machines (1) : DC Machine

1- Construction :



2- Calculating total induced emf : $e = (v \times B) \cdot l$

- Beyond pole edges emf = 0
- For segments bc , da : $e_{bc} = e_{da} = 0$ because $(v \times B) \perp l$
- For segment ab : $e_{ab} = vBl$ in page
- For segment cd : $e_{cd} = vBl$ out of page



$$\text{Total emf} = 2vBl$$

$$\text{but } v = \omega r \quad ; \quad A_p = \pi r l$$

$$\text{emf} = 2rl B \omega = \frac{2}{\pi} A_p B \omega$$

$$\therefore \text{emf} = \frac{2}{\pi} \phi \omega_m$$

It's factors ;

1- the flux in the machine 2- the speed of rotation 3- a constant represent the machine construction

3- Calculating total Torque : $F = i (l \times B)$; $\tau = Fr \sin \theta$

- Beyond pole edges $\tau = 0$
- Segments bc , cd $\tau = 0$ cuz $B \parallel l$
- Segment ab $F = Bil$ up radially $\tau = rilB$ CCW
- Segment cd $F = Bil$ down radially $\tau = rilB$ CCW

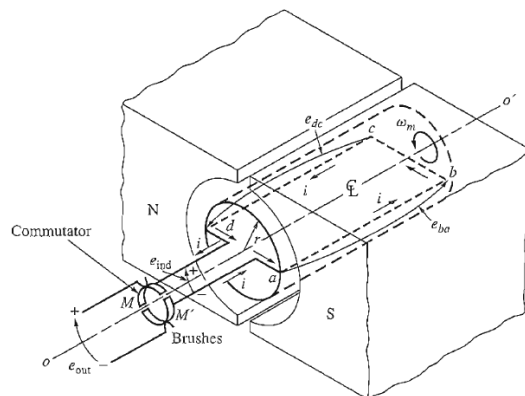
$$\tau_{total} = 2 rilB$$

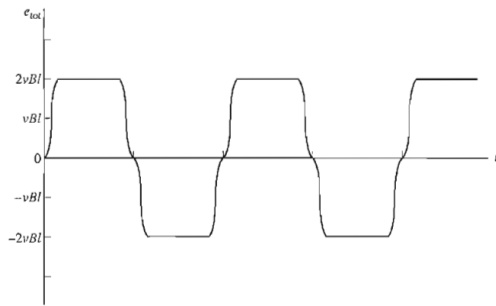
$$\tau = \frac{2}{\pi} \phi i$$

It's factors ;

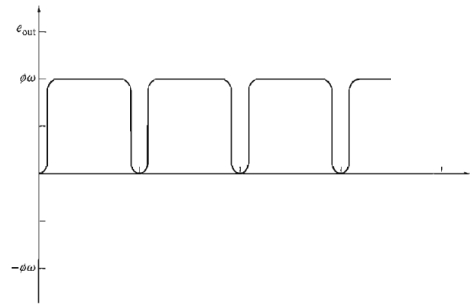
1- the flux in the machine 2- the current in machine 3- a constant represent the machine construction

4- Commutation





Before



After

Equations :

$$e_{ind} = V - IR \quad (M)$$

$$e_{ind} = V + IR \quad (G)$$

$$P = iV$$

$$P = T \omega$$

The Rotor Coils

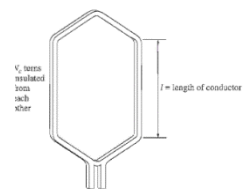
$$Z = 2 C N_c$$

number of conductors on rotor = 2 * Number of coils * Number of turns per coil

Electrical and mechanical angle : $\theta_e = \frac{P}{2} \theta_m$

If coil's $\theta_e = 180^\circ$ it's **full-pitch coil** voltage on each side are same in magnitude opposite is direction

If coil's $\theta_e < 180^\circ$ it's **fractional-pitch coil, chorded winding** it's amount is described by pitch factor $p = \frac{\theta_e}{180^\circ} \times 100 \%$



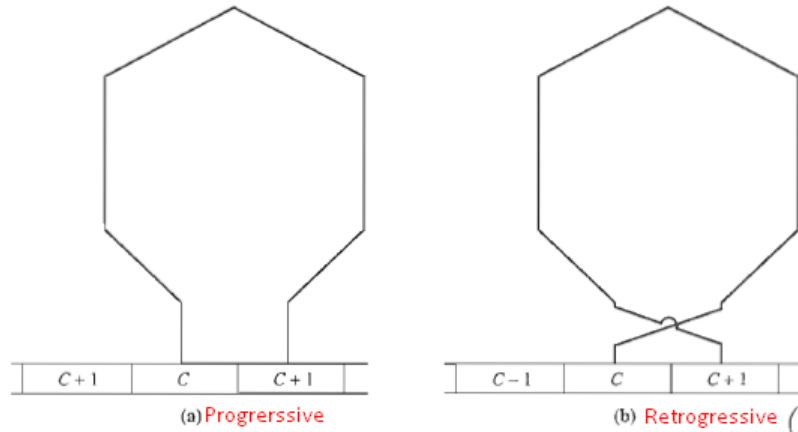
In **double layer**, all the windings are woven together **increasing mechanical strength** and **uniformity** of the final structure.

Connection to commutator segment

commutator pitch y_c : The distance (in number of segments) between the commutator segments to which the two ends of a coil are connected

Progressive vs Retrogressive

If everything else is identical, the direction of rotation of a progressive-wound rotor will be opposite to the direction of rotation of a retrogressive-wound rotor.



PLEX

Simplex : a single, complete, closed winding wound on a rotor

Duplex : a rotor with two complete and independent sets of rotor windings. If a rotor has a duplex winding, then each of the windings will be associated with every other commutator segment: One winding will be connected to segments 1, 3, 5, etc., and the other winding will be connected to segments 2, 4, 6, etc.

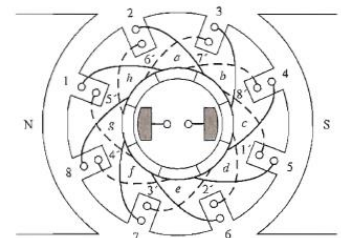
a **triplex** winding will have three complete and independent sets of windings, each winding connected to every third commutator segment on the rotor. Collectively, all armatures with more than one set of windings are said to have **multiplex** windings.

Sequence of Winding : Lap , Wave & frog leg(lap and wave)

LAP

(SIMPLEX LAP)

A simplex lap winding is a rotor winding consisting of coils containing one or more turns of wire with the two ends of each coil coming out at adjacent commutator segments



$$\text{No. of Brushes} = \text{No. of Poles}$$

$$\text{No. of Current Paths} = \text{No. of Poles}$$

$$\frac{C}{P} = \text{no of coils per parallel current path}$$

Disadvantage : Since all the paths are connected in parallel, the result will be a **circulating current** flowing out some of the brushes in the machine and back into others.

Solution : Equalizers are bars located on the rotor of a lap-wound dc machine that short together points at the same voltage

GENERALLY for m-plex lap winding

$$y_c = \pm m$$

$$a = mP$$

Photos

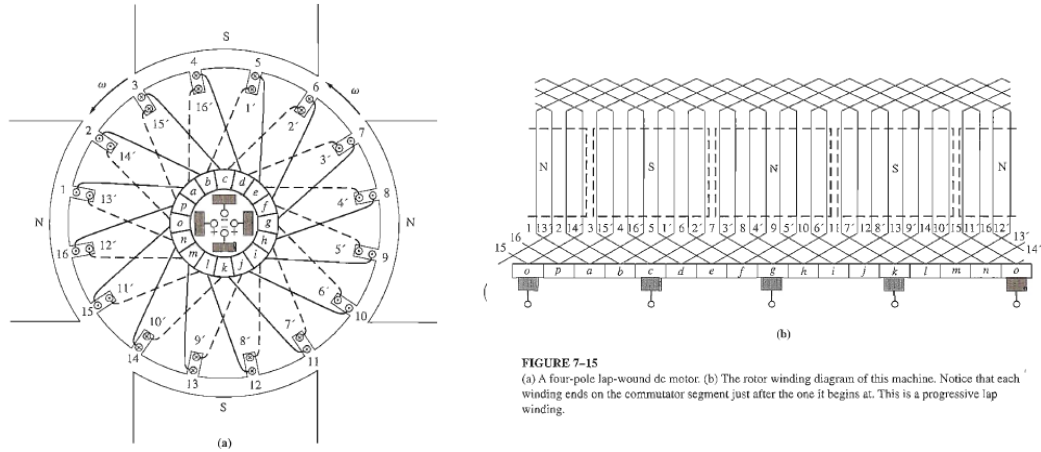
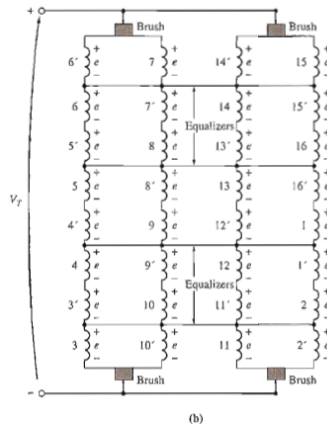
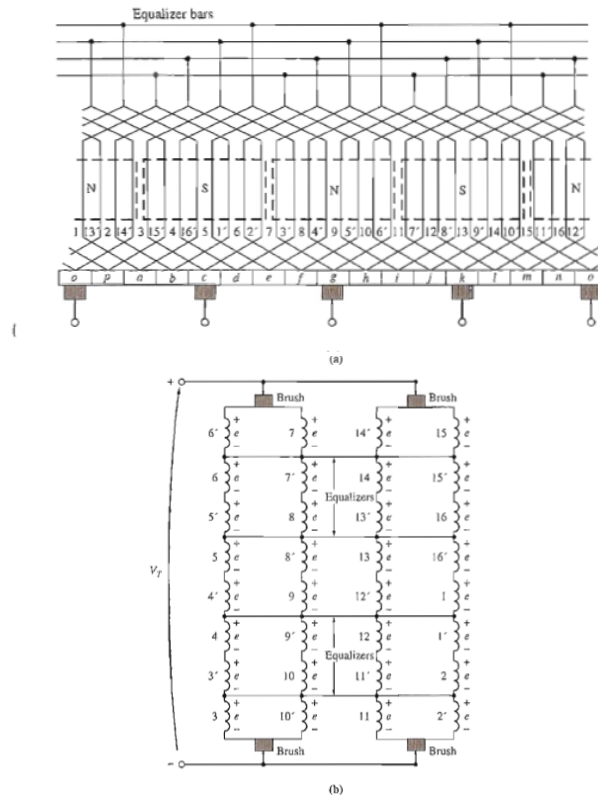


FIGURE 7-15
(a) A four-pole lap-wound dc motor. (b) The rotor winding diagram of this machine. Notice that each winding ends on the commutator segment just after the one it begins at. This is a progressive lap winding.

DC MACHINERY FUNDAMENTALS 467



(WAVE Winding)(simplex)

- In a simplex wave winding, there are only two current paths.
- There are $C/2$ (or one-half of the windings) in each current path.
- general, if there are P poles on the machine, then there are

$P/2$ coils in series between adjacent commutator segments.

Progressive : If the $(P/2)$ th coil is connected to the segment ahead of the first coil

Retrogressive : If the $(P/2)$ th coil is connected to the segment behind the first coil

- $y_c = \frac{2(C \pm 1)}{P} \dots a = 2m$
 - There is only **2 Brushes**

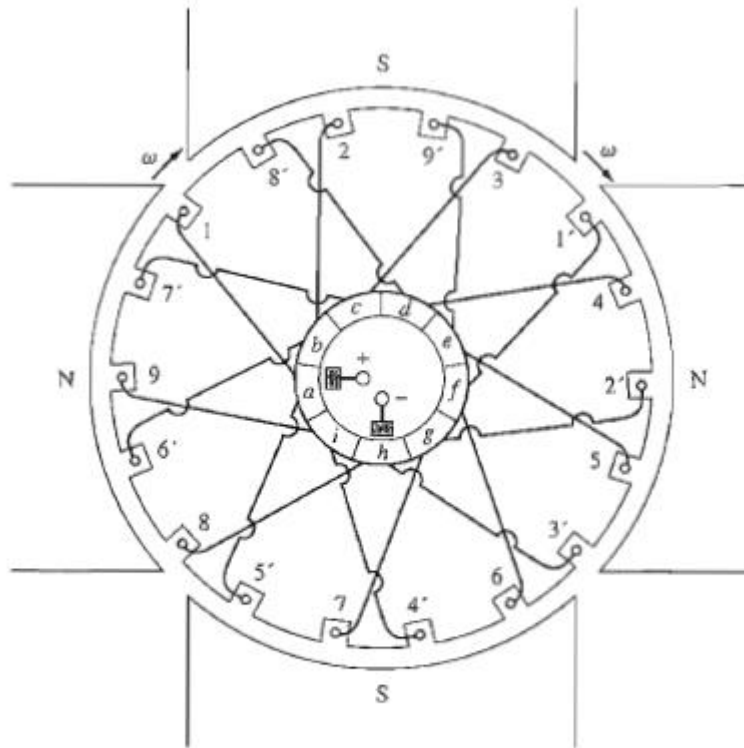


FIGURE 7-20
A simple four-pole wave-wound dc machine.

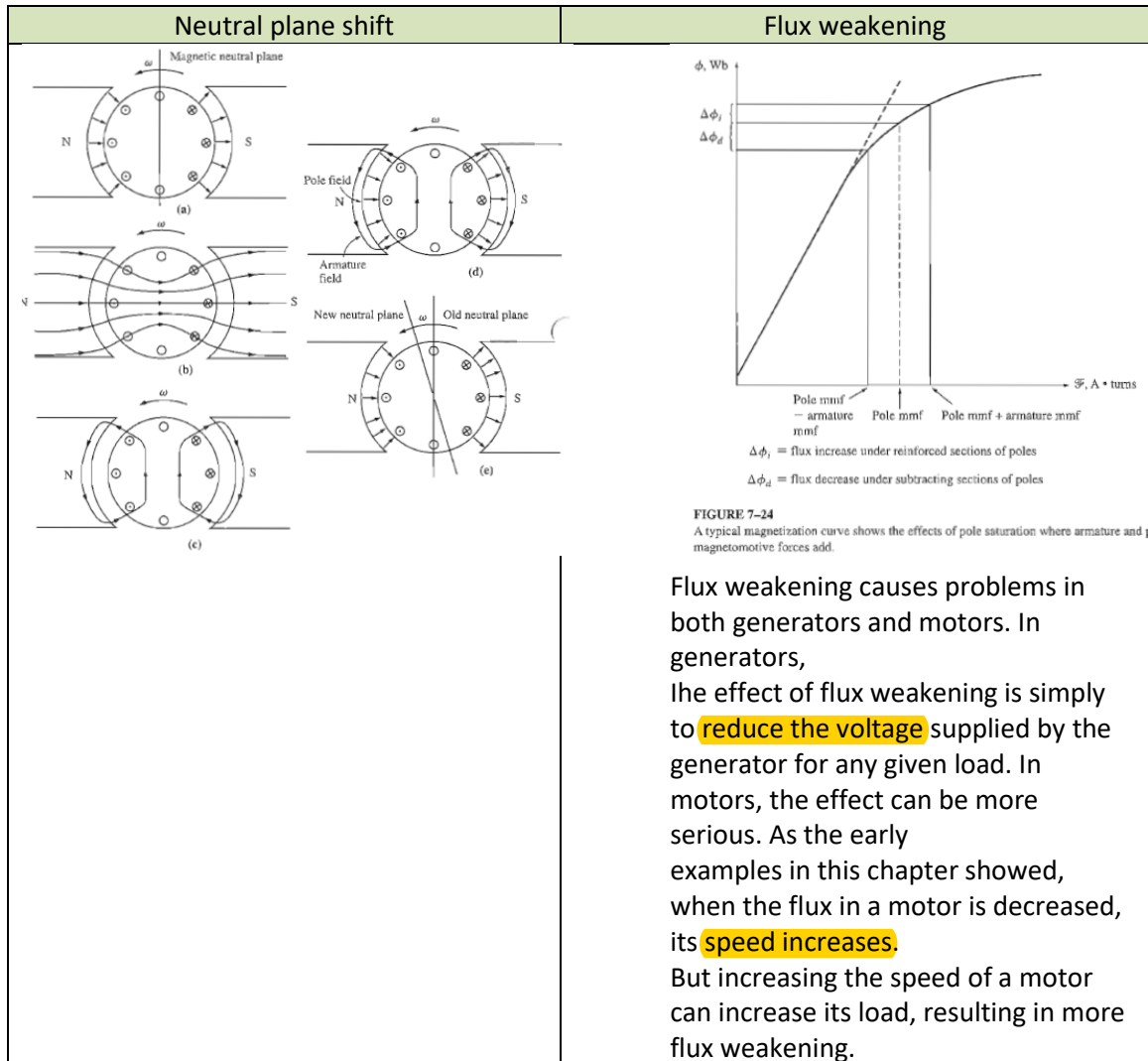
Frog Leg

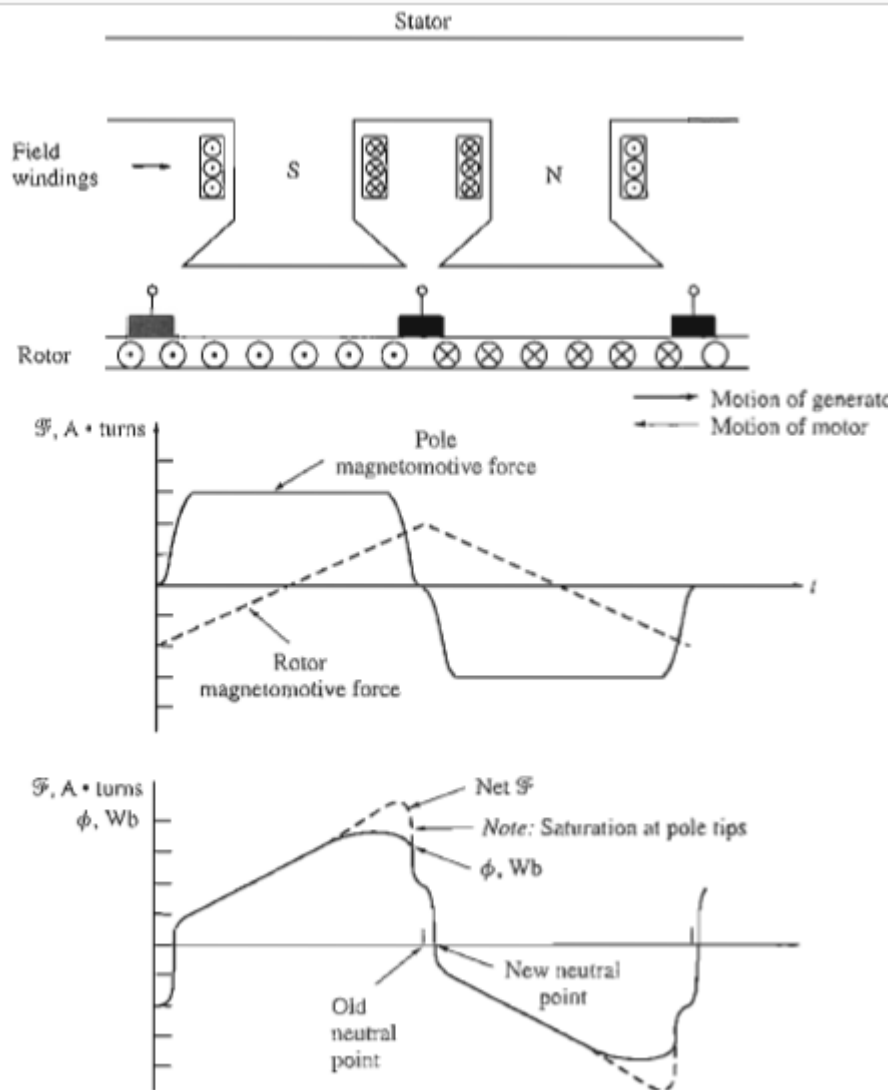
$$a = 2Pm_{lap}$$

PROBLEMS WITH COMMUTATION

- 1- Armature Reaction (a- neutral plane shift b- flux weakening)
- 2- $L \, di/dt$

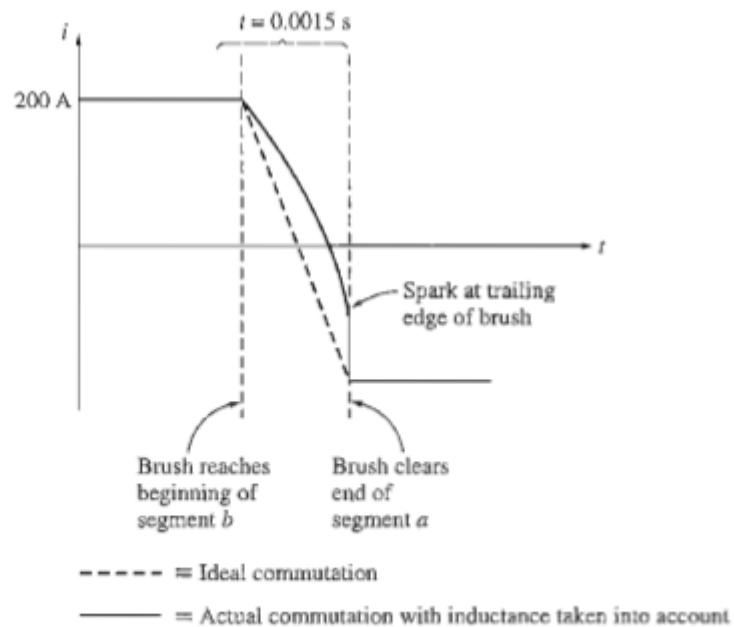
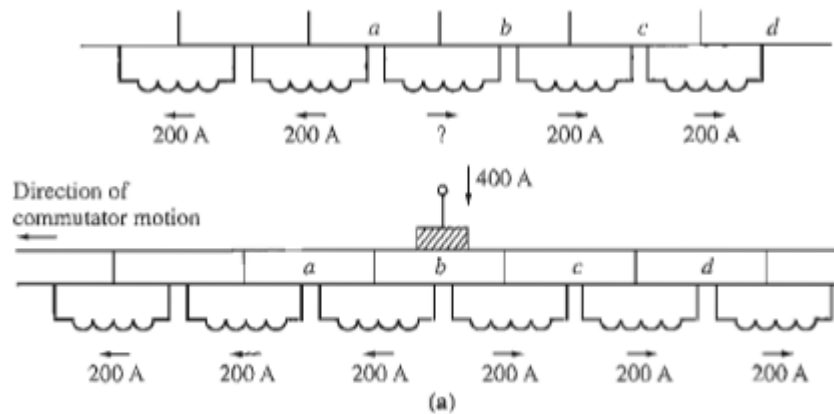
Armature Reaction





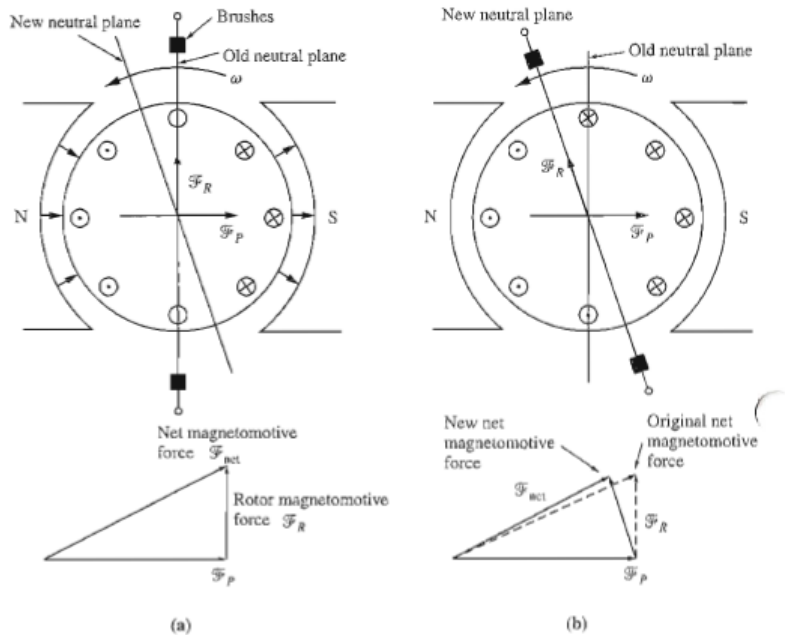
$L di/dt$ (Inductive Kick)

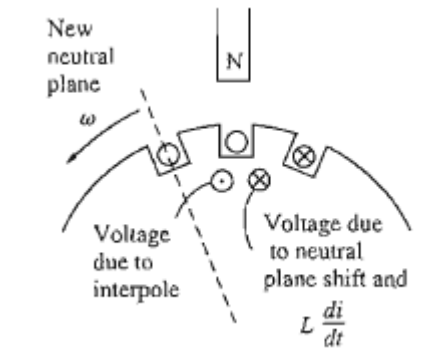
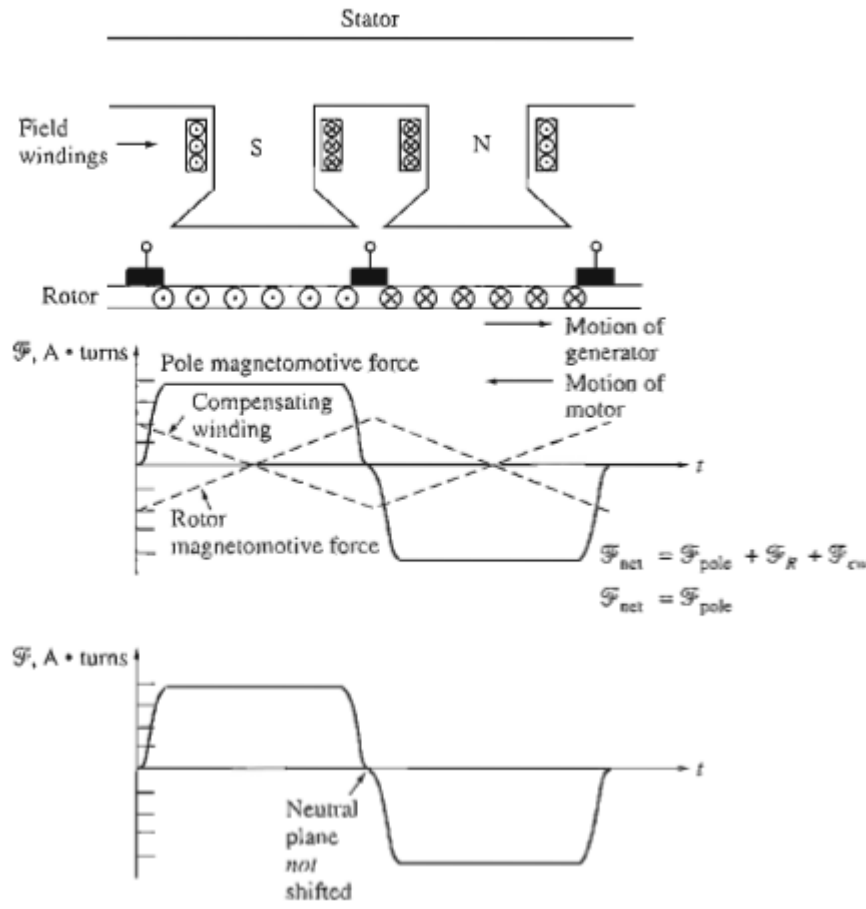
With even a tiny inductance in the loop, a very significant inductive voltage kick ($v = L di/dt$) will be induced in the shorted commutator segment. This high voltage naturally causes sparking at the brushes of the machine, resulting in the same arcing problems that the neutral-plane shift causes.



(b)

Solutions to the Problems with Commutation

Brush shifting	Just to shift brush position (by a person) according to new position to fix $L \, di/dt$ problems 1- Aggravated Flux weakening 2- The rotor magnetomotive force now has a vector component that opposes the magnetomotive force from the poles 3- The change in armature current distribution causes the flux to bunch up even more at the saturated parts of the pole faces. <i>brush shifting is only used in very small machines that always run as motors. This is done because better solutions to the problem are simply not economical in such small motors</i>  Diagram (a) shows a motor with brushes at the original neutral plane. The rotor magnetomotive force $\mathcal{F}_R$ is in phase with the pole flux $\mathcal{F}_P$. The net magnetomotive force $\mathcal{F}_{net}$ is the vector sum of $\mathcal{F}_R$ and $\mathcal{F}_P$. Diagram (b) shows the brushes shifted to the new neutral plane. The rotor magnetomotive force $\mathcal{F}_R$ is now out of phase with $\mathcal{F}_P$, and the net magnetomotive force $\mathcal{F}_{net}$ is reduced.						
Commutating poles or interpoles	the voltage in the wires undergoing commutation can be made zero, then there will be no sparking at the brushes using interpoles over conductor undergoing commutation. - It doesn't affect A.R. or flux weakening - Works for a large range of loads and motors and generators - Cancels sparking ($L \, di/dt$) <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; text-align: center;">Motor</th><th style="width: 50%; text-align: center;">Generator</th></tr> </thead> <tbody> <tr> <td style="text-align: center;">Neutral plane shifts against rotation</td><td style="text-align: center;">Neutral plane shifts same as rotation</td></tr> <tr> <td style="text-align: center;">The interpoles must be of the same polarity as the previous main pole</td><td style="text-align: center;">The in interpoles must be of the same polarity as the next upcoming main pole</td></tr> </tbody> </table>	Motor	Generator	Neutral plane shifts against rotation	Neutral plane shifts same as rotation	The interpoles must be of the same polarity as the previous main pole	The in interpoles must be of the same polarity as the next upcoming main pole
Motor	Generator						
Neutral plane shifts against rotation	Neutral plane shifts same as rotation						
The interpoles must be of the same polarity as the previous main pole	The in interpoles must be of the same polarity as the next upcoming main pole						

		 New neutral plane ω Voltage due to interpole Voltage due to neutral plane shift and $L \frac{di}{dt}$
Compensating windings	We machine a compensating winding that is connected in series with the rotor winding it eliminates flux weakening  Stator Field windings S N Rotor Motion of generator Motion of motor $\mathcal{F}, A \cdot \text{turns}$ Pole magnetomotive force Compensating winding Rotor magnetomotive force $\mathcal{F}_{net} = \mathcal{F}_{pole} + \mathcal{F}_R + \mathcal{F}_{cw}$ $\mathcal{F}_{net} = \mathcal{F}_{pole}$ Neutral plane not shifted	Disadvantages : 1- Expensive 2- Doesn't eliminate $L \frac{di}{dt}$ (so we will need –not very strong- interpoles)

THE INTERNAL GENERATED VOLTAGE

It's factors ;

1- the flux in the machine 2- the speed of rotation 3- a constant represent the machine construction

$$E_A = \frac{ZvBl}{a} \quad E_A = \frac{Zr\omega_m Bl}{a}$$

$$\phi = BA_P \quad A = 2\pi rl \quad A_P = \frac{A}{P} = \frac{2\pi rl}{P} \quad \phi = BA_P = \frac{B(2\pi rl)}{P} = \frac{2\pi rlB}{P}$$

$$E_A = \frac{Zr\omega_m Bl}{a}$$

$$= \left(\frac{ZP}{2\pi a} \right) \left(\frac{2\pi rlB}{P} \right) \omega_m$$

$$E_A = \frac{ZP}{2\pi a} \phi \omega_m$$

$$E_A = K \phi \omega_m$$

$$K = \frac{ZP}{2\pi a}$$

$$\omega_m = \frac{2\pi}{60} n_m$$

$$E_A = K' \phi n_m$$

$$K' = \frac{ZP}{60a}$$

INDUCED TORQUE EQUATIONS

It's factors ;

1- the flux in the machine 2- the current in machine 3- a constant represent the machine construction

$$\tau_{\text{cond}} = rI_{\text{cond}}lB \quad I_{\text{cond}} = \frac{I_A}{a} \quad \tau_{\text{cond}} = \frac{rI_A lB}{a}$$

$$\tau_{ind} = \frac{ZrlBI_A}{a}$$

$$\phi = BA_p = \frac{B(2\pi rl)}{P} = \frac{2\pi rlB}{P}$$

$$\tau_{ind} = \frac{ZP}{2\pi a} \phi I_A$$

$$\tau_{ind} = K \phi I_A$$

$$K = \frac{ZP}{2\pi a}$$

- For better accuracy for emf and T we use no of conductors under pole faces instead of total number of conductors in these relations

POWER FLOW AND LOSSES IN DC MACHINES

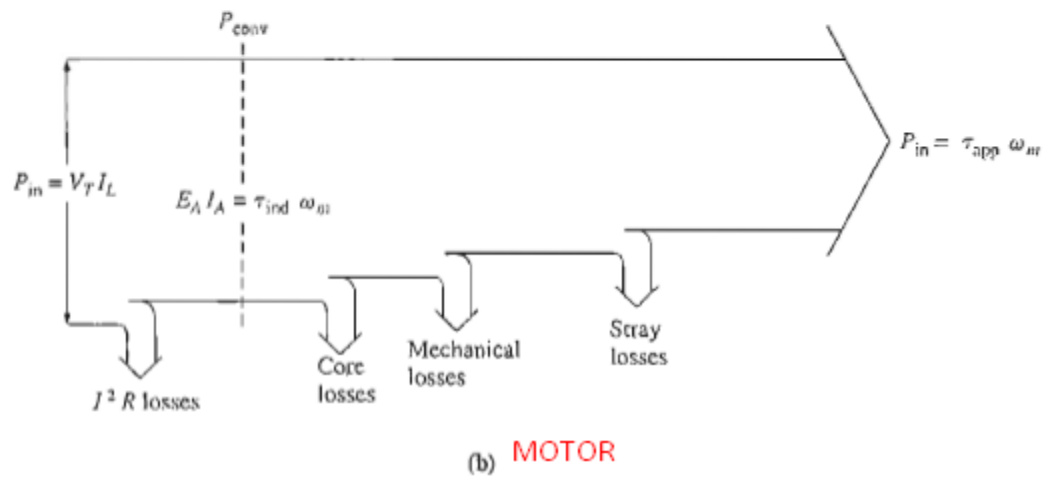
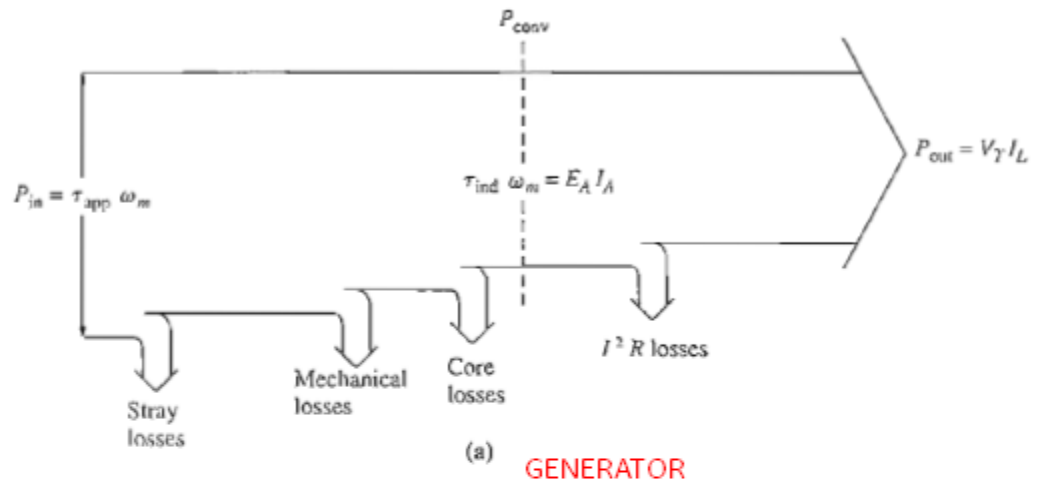
$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{out} - P_{loss}}{P_{in}} \times 100\%$$

The Losses in DC Machines

Electrical or copper losses (I^2R losses)	Armature loss: $P_A = I_A^2 R_A$ Field loss: $P_F = I_F^2 R_F$
Brush losses	$P_{BD} = V_{BD} I_A$ $V_{BD} \cong 2V$
Core losses	$P_{iron} \propto B^2 \propto n^{1.5}$
Mechanical losses	1- Friction losses are losses caused by the friction of the bearings in the machine 2- Windage losses are caused by the friction between the moving parts of the machine and the air inside the motor's casing $P_{mech} \propto n^3$
Stray load losses	Stray losses are losses that cannot be placed in one of the previous categories.

The Power-Flow Diagram



$$P_{conv} = \tau_{ind} \omega_m$$

$$P_{conv} = E_A I_A$$

CH : 8

Speed Regulation

$$SR = \frac{\omega_{m,nl} - \omega_{m,fl}}{\omega_{m,fl}} \times 100\%$$

$$SR = \frac{n_{m,nl} - n_{m,fl}}{n_{m,fl}} \times 100\%$$

The magnitude- of the speed Reg. approximately **how steep the slope of the torque-speed curve is.**

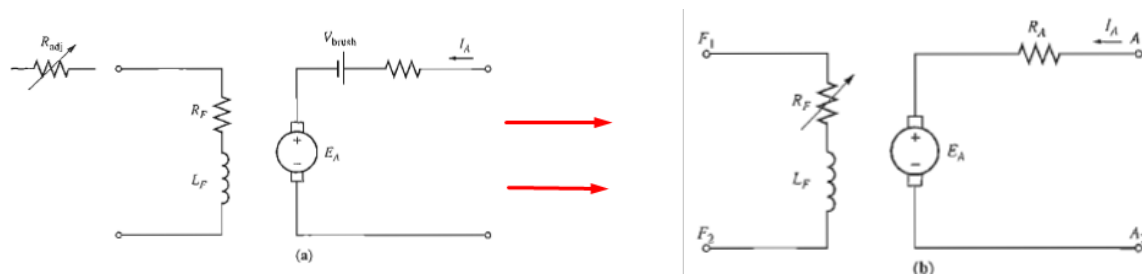
Positive Speed Regulation means that a motor's .speed drops with increasing load,

Negative Speed Regulation means a motor's speed increases with increasing Load.

major types of de motors in general use:

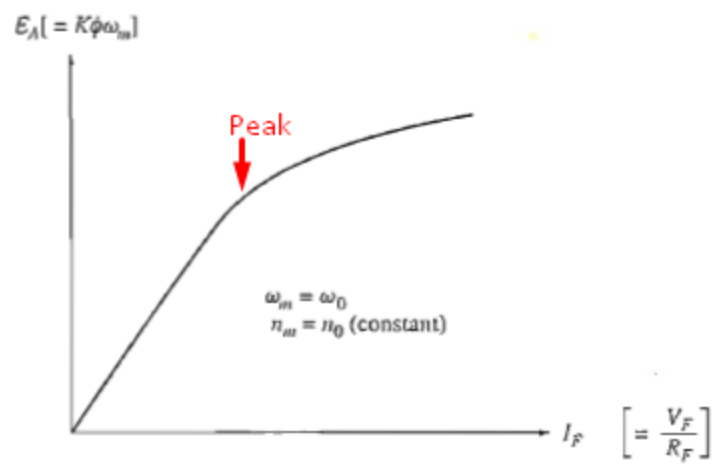
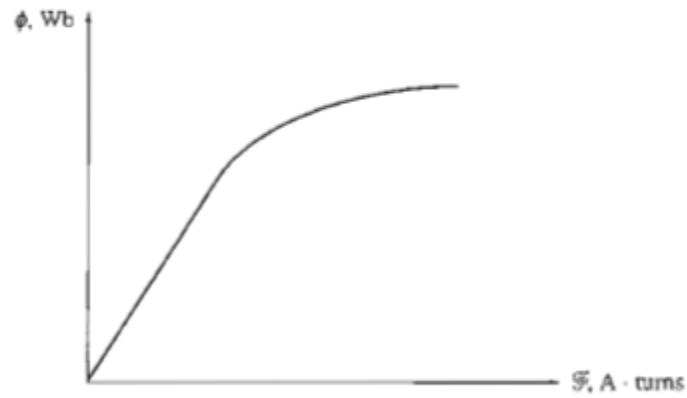
1. The separately excited de motor
2. The shunt de motor
3. The permanent-magnet de motor
4. The series de motor
5. The compounded de motor

THE EQUIVALENT CIRCUIT OF A DCMOTOR

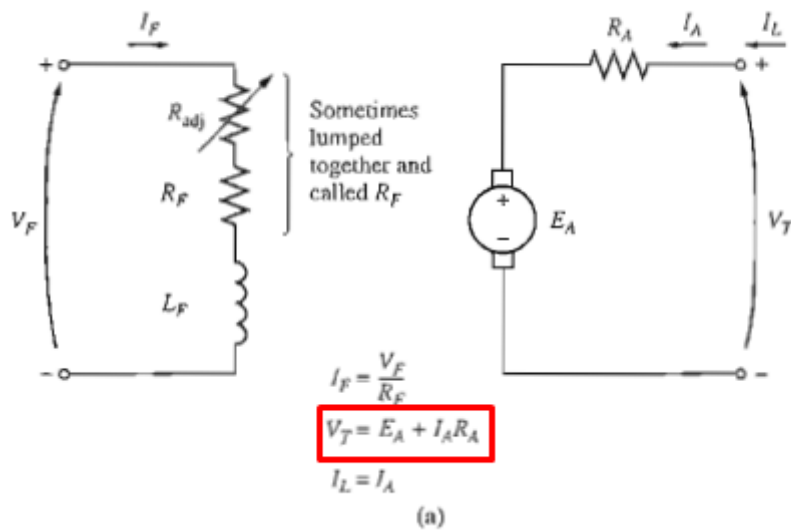


THE MAGNETIZATION CURVE OF A DC MACHINE

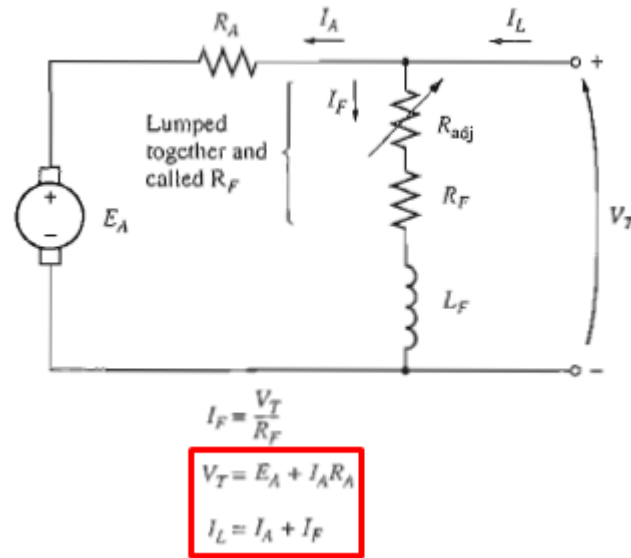
$$E = k \phi \omega_m \rightarrow E \propto \phi \rightarrow \phi \propto I_F \propto \mathcal{F}$$



SEPARATELY EXCITED DC MOTOR



SHUNT EXCITED DC MOTOR



The Terminal Characteristic of a Shunt DC Motor

Terminal Characteristics is plot between the output quantities of a machine

For DC Motor plot of its **output torque versus speed**.

$$V_T = E_A + I_A R_A \quad (8-3)$$

The induced voltage $E_A = K\phi\omega_m$, so

$$V_T = K\phi\omega_m + I_A R_A \quad (8-4)$$

Since $\tau_{ind} = K\phi I_A$, current I_A can be expressed as

$$I_A = \frac{\tau_{ind}}{K\phi} \quad (8-5)$$

Combining Equations (8-4) and (8-5) produces

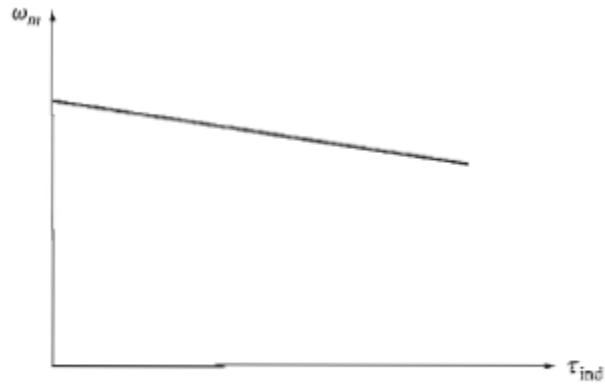
$$V_T = K\phi\omega_m + \frac{\tau_{ind}}{K\phi} R_A \quad (8-6)$$

Finally, solving for the motor's speed yields

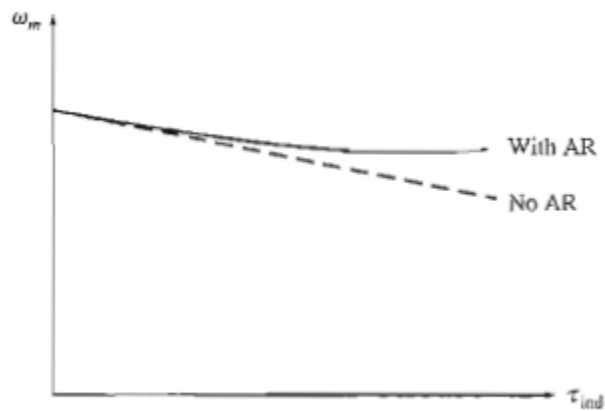
$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \tau_{ind} \quad (8-7)$$

5 خطوات يعني يتسمعوا 5 خطوات عشان الدكتور طالب كده

رسمها:



(a)

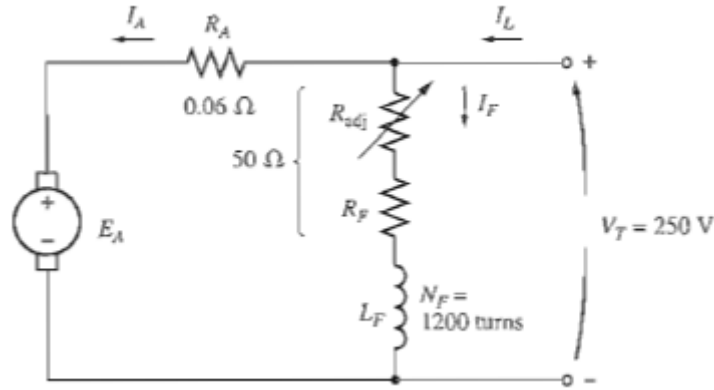


(b)

Notes :

- 1- The terminal voltage supplied by the dc power source is assumed to be constant
- 2- When the load increases (Torque increases) the speed decrease
- 3- If a motor has armature reaction, then as its load increases, the flux-weakening effects reduce its flux.
- 4- If a shunt dc motor has compensating windings so that its flux is constant regardless of load, and the motor's speed and armature current are known at any one value of load, then it is possible to calculate its speed at any other value of load, as long as the armature current at that load is known or can be determined

LINEAR ANALYSIS OF SHUNT DC MOTOR (WITHOUT ARMATURE REACTION)
(with compensating winding)



$$E_A = K' \phi n_m$$

$$\therefore \frac{E_{A2}}{E_{A1}} = \frac{K' \phi n_{m2}}{K' \phi n_{m1}}$$

$$\therefore n_{m2} = \frac{E_{A2}}{E_{A1}} n_{m1}$$

يعني لو عندي سرعه و جهد ال no load وعندني الجهد في أي حاله اقدر اجيب السرعه
طب ازاي اجيب الجهد بالمعطيات المختلفه

$$I_A = I_L - I_F = I_L - \frac{V_T}{R_F}$$

$$E_A = V_T - I_A R_A$$

plotting τ vs n_m

نحتاج العزم المقابل لكل سرعه نحصل عليها من العلاقه

$$p_{conv} = E_A I_A = \tau_{in} \omega$$

$$\tau_{in} = \frac{E_A I_A}{\omega} = \frac{E_A I_A}{n_m * \frac{2\pi}{60}}$$

NON-LINEAR ANALYSIS OF SHUNT DC MOTOR (WITH ARMATURE REACTION)
(without compensating winding)

the magnetization curve of the machine must be used to accurately determine its E_A for a given magnetomotive force. The two principal contributors to the magnetomotive force in the machine are its

Magnetization curve is between E_A and I_F for a given ω so the effect of changing field current can be determined directly from it

If it has armature reaction the net magnetomotive force

$$\mathcal{F}_{net} = N_f I_f - \mathcal{F}_{AR}$$

$$\therefore I_F^* = I_F - \frac{\mathcal{F}_{AR}}{N_F} = \frac{V_T}{R_F} - \frac{\mathcal{F}_{AR}}{N_F}$$

I_F^* Effective current هي اللي بدخل بيها على الماجنتيزاشن كيرف

طب في مشكله ان الماجنتيزاشن كيرف اقدر ادخل بيه بال Effective Current واطلع بجهد E_{A0} عند سرعه ال rated بس انا شغال عند سرعه ثانيه ازاي اجيب السرعه اللي انا عاوزها

بسيطه عوض في القانون ده

$$\frac{E_A}{E_{A0}} = \frac{n_m}{n_0}$$

اذن الخطوات زي اللي فانت

$$I_A = I_L - I_F = I_L - \frac{V_T}{R_F}$$

$$E_A = V_T - I_A R_A$$

then get effective current : $I_F^* = I_F - \frac{\mathcal{F}_{AR}}{N_F}$ use it to get E_{A0} of n_{m0}

then get the n_m from $n_m = \frac{E_A}{E_{A0}} n_0$

To get torque : $T_{ind} = \frac{E_A I_A}{\omega_m}$

To get the new armature reaction $\mathcal{F}_{ar(new)} = \mathcal{F}_{R(old)} * \frac{I_{L(new)}}{I_{L(old)}}$

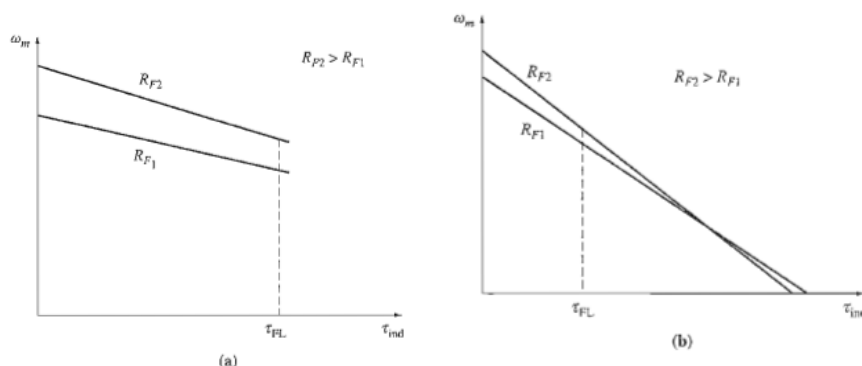
Notice that the speed of the motor with armature reaction is higher than the speed of the motor with no armature reaction. This relative increase in speed is due to the flux weakening in the machine with armature reaction.

Speed Control of Shunt DC Motors

1. Adjusting the field resistance R_F (and thus the field flux)
2. Adjusting the terminal voltage applied to the armature.
3. Inserting a resistor in series with the armature circuit. (*NOT COMMON*)

1- CHANGING THE FIELD RESISTANCE

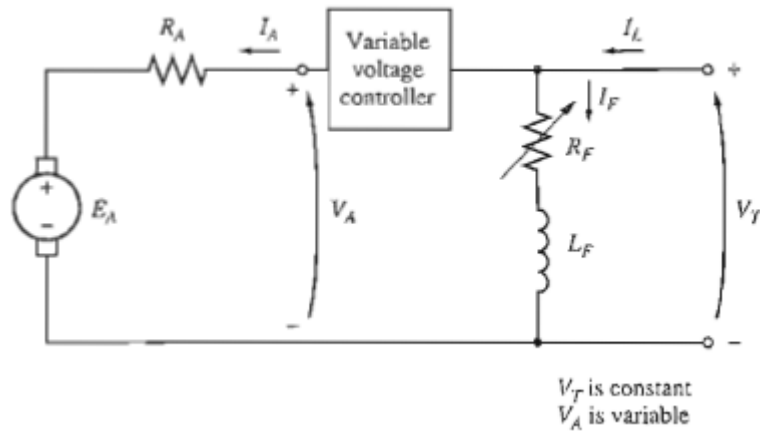
1. Increasing R_F causes $I_F (= V_T / R_F \uparrow)$ to decrease.
2. Decreasing I_F decreases ϕ .
3. Decreasing ϕ lowers $E_A (= K\phi\omega_m)$.
4. Decreasing E_A increases $I_A (= (V_T - E_A) / R_A)$.
5. Increasing I_A increases $\tau_{ind} (= K\phi I_A \uparrow)$, with the change in I_A dominant over the change in flux).
6. Increasing τ_{ind} makes $\tau_{ind} > \tau_{load}$, and the speed ω_m increases.
7. Increasing ω_m increases $E_A = K\phi\omega_m \uparrow$ again.
8. Increasing E_A decreases I_A .
9. Decreasing I_A decreases τ_{ind} until $\tau_{ind} = \tau_{load}$ at a higher speed ω_m .



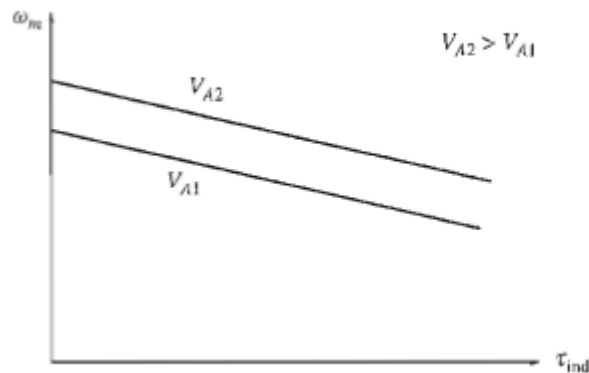
Notes :

- 1- 1 % decrease in ϕ : will 1% decrease in E_A a 49% increase in I_A
- 2- This method works in range between no load and full load in high speeds only
- 3- When the R_F increase the speed ω increase and slope becomes steep
- 4- In low speeds like in small motors this method has no effect or it will make speed slows

2- CHANGING THE ARMATURE VOLTAGE



1. An increase in V_A increases I_A [$= (V_A \uparrow - E_A)/R_A$].
2. Increasing I_A increases τ_{ind} ($= K\phi I_A \uparrow$).
3. Increasing τ_{ind} makes $\tau_{ind} > \tau_{load}$ increasing ω_m .
4. Increasing ω_m increases E_A ($= K\phi\omega_m \uparrow$).
5. Increasing E_A decreases I_A [$= (V_A \uparrow - E_A)/R_A$].
6. Decreasing I_A decreases τ_{ind} until $\tau_{ind} = \tau_{load}$ at a higher ω_m .

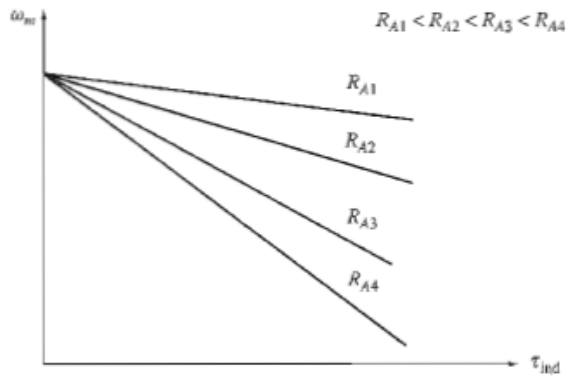


Note that the speed is shifted but the slope is the same it can be noticed from the terminal characteristic

3- INSERTING SERIES RESISTOR WITH ARMATURE

It is used in application which always operate at full speed or too expensive
Generally it's uncommon

Adding a resistance in series will increase the slope **to operate slowly of loaded**
Disadvantage: It's very wasteful because of the losses in the resistance

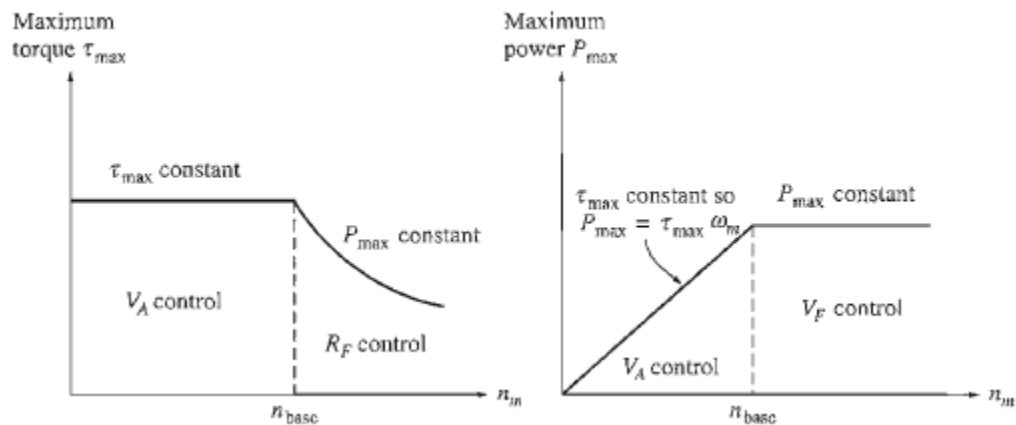


GENERAL COMPARISON

Field Resistance	- The higher $I_F \uparrow$ the slower the speed $\omega \downarrow$ - The lower $I_F \downarrow$ the higher the speed $\omega \uparrow$ - There is minimum speed ω_{Min} when I_{FMAX} - It can be used at speeds higher than the base (rated) speed
Voltage Control	- The higher $V \uparrow$ the faster the speed $\omega \uparrow$ - The lower $V \downarrow$ the lower the speed $\omega \downarrow$ - There is minimum speed ω_{Min} when I_{FMAX} - It can be used at speeds Below than the base (rated) speed

Combining the 2 methods together will get a range of 1:40 of speed control

TORQUE AND POWER LIMITS UNDER THESE 2 METHODS



في السرعات العاليه بنزود السرعه بزياده التيار على حساب العزم في حين القدرة ثابتة و التيار جايب أخره
في السرعات المنخفضه الفيض ثابت فالقدرة القسوة تتناسب طرديا مع السرعه في حين ان العزم ثابت

The Effect of an Open Field Circuit

PROBLEM :

What happens with very large field resistance / open field circuit / light field with high armature reaction
most torque speed curves makes torque increase with speed so when

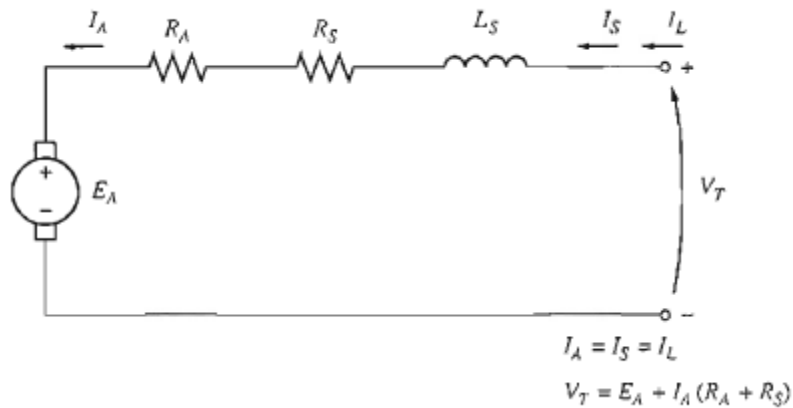
Increase speed : increase load : increase armature reaction : weakens flux : increases speed even more

The speed increase until it overspeeds in which is know as **runaway**

Solutions

- 1- Field Loss relay to disconnect the motor from the line in this case
- 2- Compensating winding to fix flux weakening
- 3- Series turns of **cumulative compounding** in the mototrs poles know as **stabilized shunt motor**

THE SERIES DC MOTOR



$$V_T = E_A + I_A(R_A + R_S)$$

It's terminal characteristic is different than the shunt motor as

The flux is directly proportional to the armature current

When load increases the flux increases too

$$\tau_{ind} = K \phi I_A$$

$$\phi = c I_A$$

$$\tau_{ind} = K \phi I_A = K c I_A^2$$

The series motor gives more torque per ampere than any other machine

Applications : starter motors , elevator motors , tractor motors , helwan metro

Terminal Characteristics of Series Motor

$$\tau_{ind} = K \phi I_A , \phi = c I_A$$

$$V_T = E_A + I_A(R_A + R_S)$$

$$I_A = \sqrt{\frac{\tau_{ind}}{Kc}}$$

$$V_T = K \phi \omega_m + \sqrt{\frac{\tau_{ind}}{Kc}} (R_A + R_S)$$

$$I_A = \frac{\phi}{c}$$

$$\tau_{\text{ind}} = \frac{K}{c} \phi^2$$

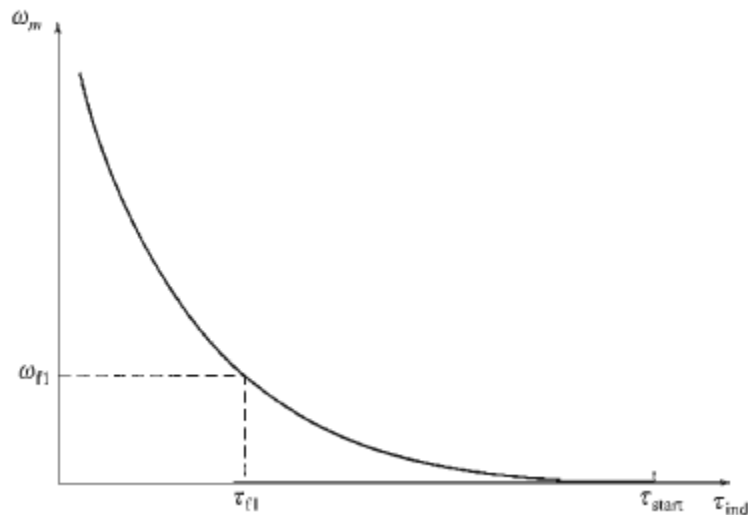
$$\phi = \sqrt{\frac{c}{K}} \sqrt{\tau_{\text{ind}}}$$

$$V_T = K \sqrt{\frac{c}{K}} \sqrt{\tau_{\text{ind}}} \omega_m + \sqrt{\frac{\tau_{\text{ind}}}{Kc}} (R_A + R_S)$$

$$\sqrt{Kc} \sqrt{\tau_{\text{ind}}} \omega_m = V_T - \frac{R_A + R_S}{\sqrt{Kc}} \sqrt{\tau_{\text{ind}}}$$

$$\omega_m = \frac{V_T}{\sqrt{Kc} \sqrt{\tau_{\text{ind}}}} - \frac{R_A + R_S}{Kc}$$

$$\omega_m = \frac{V_T}{\sqrt{Kc}} \frac{1}{\sqrt{\tau_{\text{ind}}}} - \frac{R_A + R_S}{Kc}$$



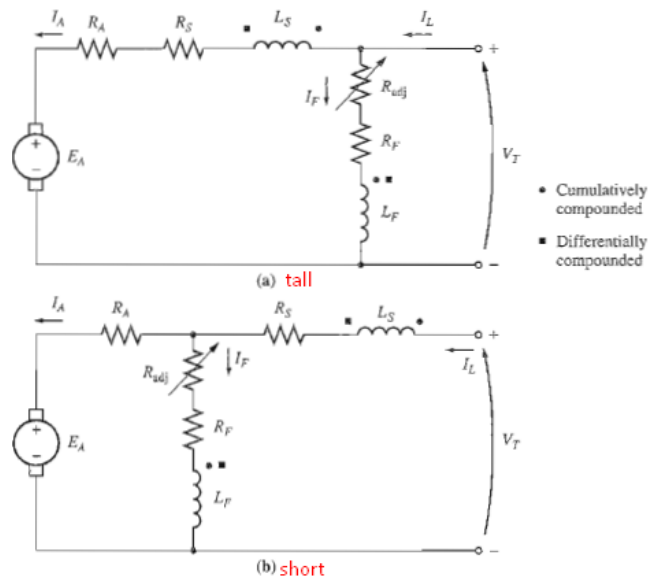
Problem : when torque = 0 the speed is ∞ but it can't be zero and we always load it

SPEED CONTROL OF SERIES DC MOTOR

- 1- Voltage control : when the terminal voltage is increased the higher the speed for any given torque

- 2- Series Resistance adding : not very good wasteful of power , used intermittent period during the startup of some motors

THE COMPOUND DC MOTOR



$$V_T = E_A + I_A(R_A + R_S)$$

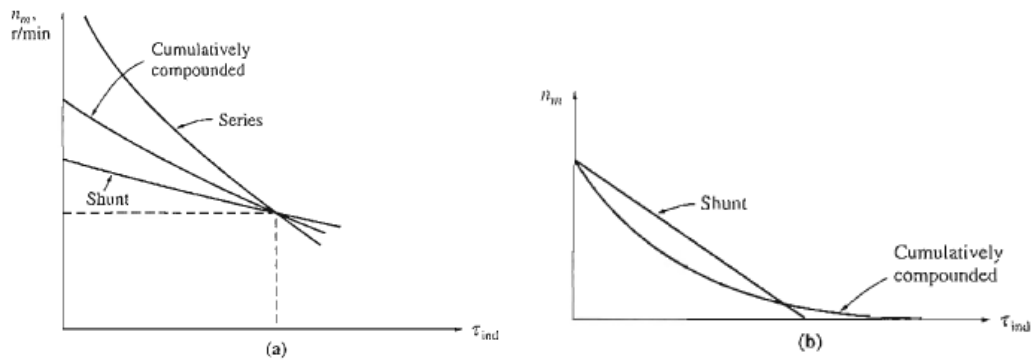
$$I_A = I_L - I_F$$

$$I_F = \frac{V_T}{R_F}$$

$$\mathcal{F}_{\text{net}} = \mathcal{F}_F \pm \mathcal{F}_{SE} - \mathcal{F}_{AR}$$

$$I_F^* = I_F \pm \frac{N_{SE}}{N_F} I_A - \frac{\mathcal{F}_{AR}}{N_F}$$

The Torque- Speed Characteristic of a Cumulatively Compounded DC Motor

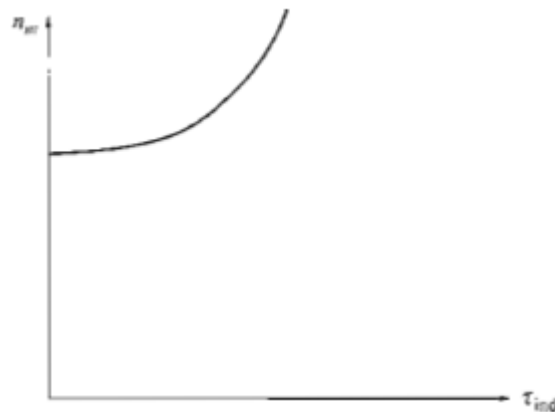


It has a starting torque higher than the shunt and less than the series

It's has the advantages :

- 1- A high starting torque (of series)
- 2- Doesn't overspeed at no load (as shunt)
- 3- At light loads it behaves as the shunt but at high loads it behaves as series

The Torque-Speed Characteristic of a Differentially Compounded DC Motor



load on the motor increases, I_A increases and the flux in the motor decreases.

النوع ده زي الزيت ملوش أي ستين لازمه في الحياه ، بيحاول ي اوفر سبيد على طول وبيكسر نفسه زي ما الكيرف موضح ده غير ان أصلا ظروف ال starting صعبه جدا بيحرق تيار كثير وميلفش او بيلف في الاتجاه العلط ببطء اثناء ما بيولع في نفسه جوا

The Nonlinear Analysis of Componded DC Motors

$$E_A = V_T - I_A(R_A + R_S)$$

$$I_F^* = I_F + \frac{N_{SE}}{N_F} I_A - \frac{\mathcal{F}_{AR}}{N_F}$$

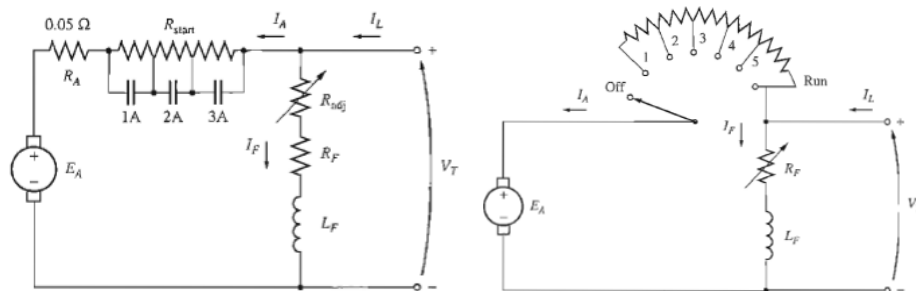
$$n_m = \frac{E_A}{E_{A0}} n_0$$

Speed Control in the Cumulatively Compounded DC Motor

1. Change the field resistance R_F .
2. Change the armature voltage V_A .
3. Change the armature resistance R_A .

DC MOTOR STARTERS

1. To protect the motor against damage due to short circuits in the equipment
2. To protect the motor against damage from long-term overloads
3. To protect the motor against damage from excessive starting currents
4. To provide a convenient manner in which to control the operating speed of the motor



There was manual but it had a human error

Then there is contactor new one

We have to design 1- number 2- size 3- when to be cut off

This is how

$$R_{tot} = R_1 + R_2 + \dots + R_A$$

$$R_{tot,i} = R_{i+1} + \dots + R_A \quad Ex : R_{tot} = R_1 + R_2 + R_3 + R_A$$

$$R_{tot,1} = R_2 + R_3 + R_A$$

$$R_{tot} = \frac{V_T}{I_{max}}$$

$$I_A = \frac{V_T - E_A}{R_{tot}} = I_{min}$$

We switch the first stage out R1 when

$$This \text{ happens when } E_A = V_T - I_A R_{tot}$$

$$I_A = \frac{V_T - E_A}{R_{tot,i}} = I_{max}$$

After switching it out the current must jump to

$$I_{min} R_{tot} = V_T - E_A = I_{max} R_{tot,i}$$

$$R_{tot,i} = \frac{I_{min}}{I_{max}} R_{tot}$$

Then ,

$$R_{tot,n} = \left(\frac{I_{min}}{I_{max}} \right)^n R_{tot}$$

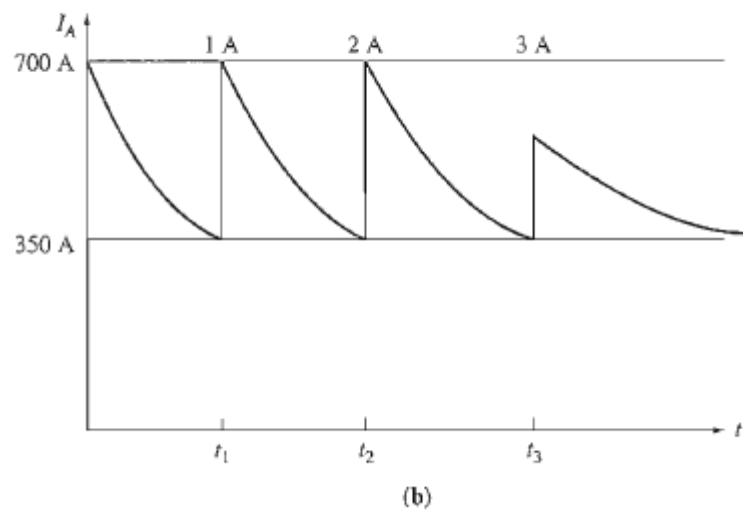
So ,

$$R_A = R_{tot,n} = \left(\frac{I_{min}}{I_{max}} \right)^n R_{tot}$$

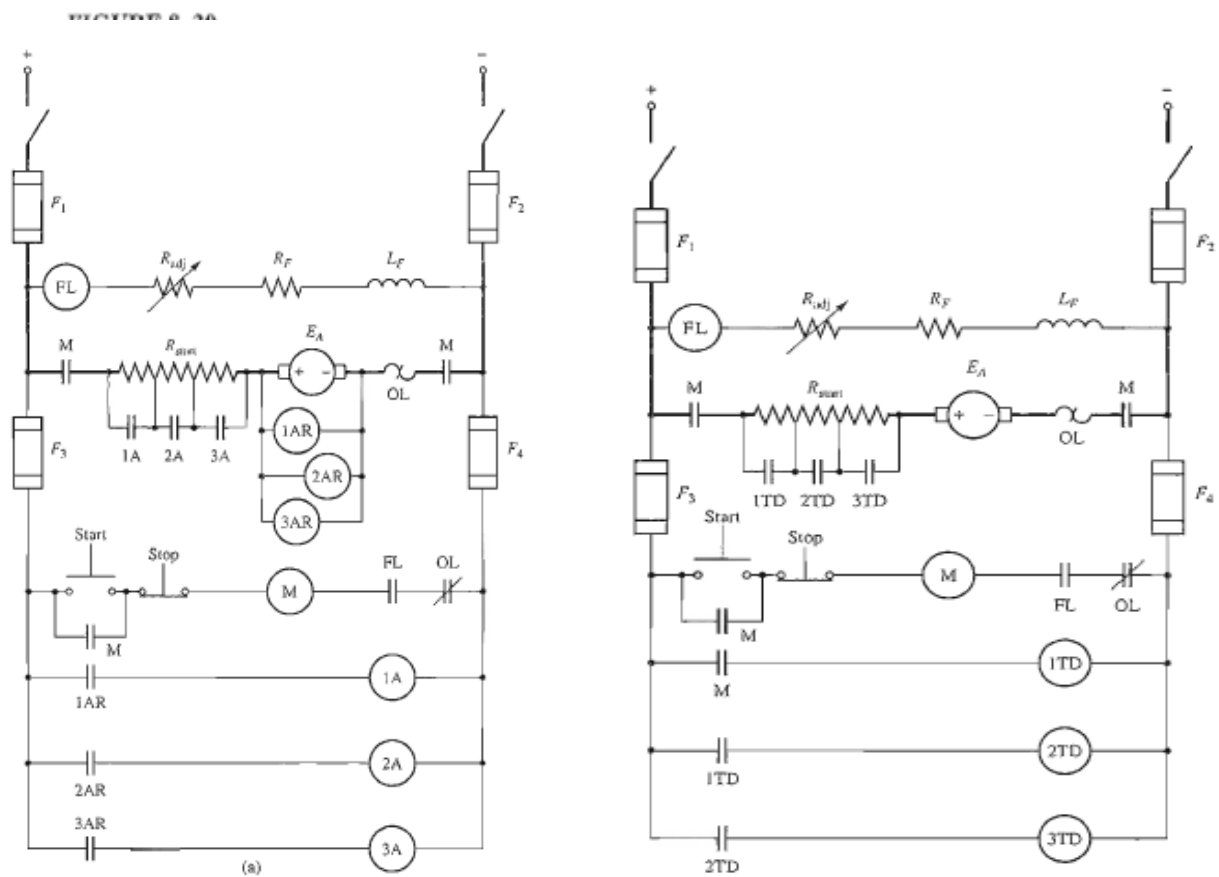
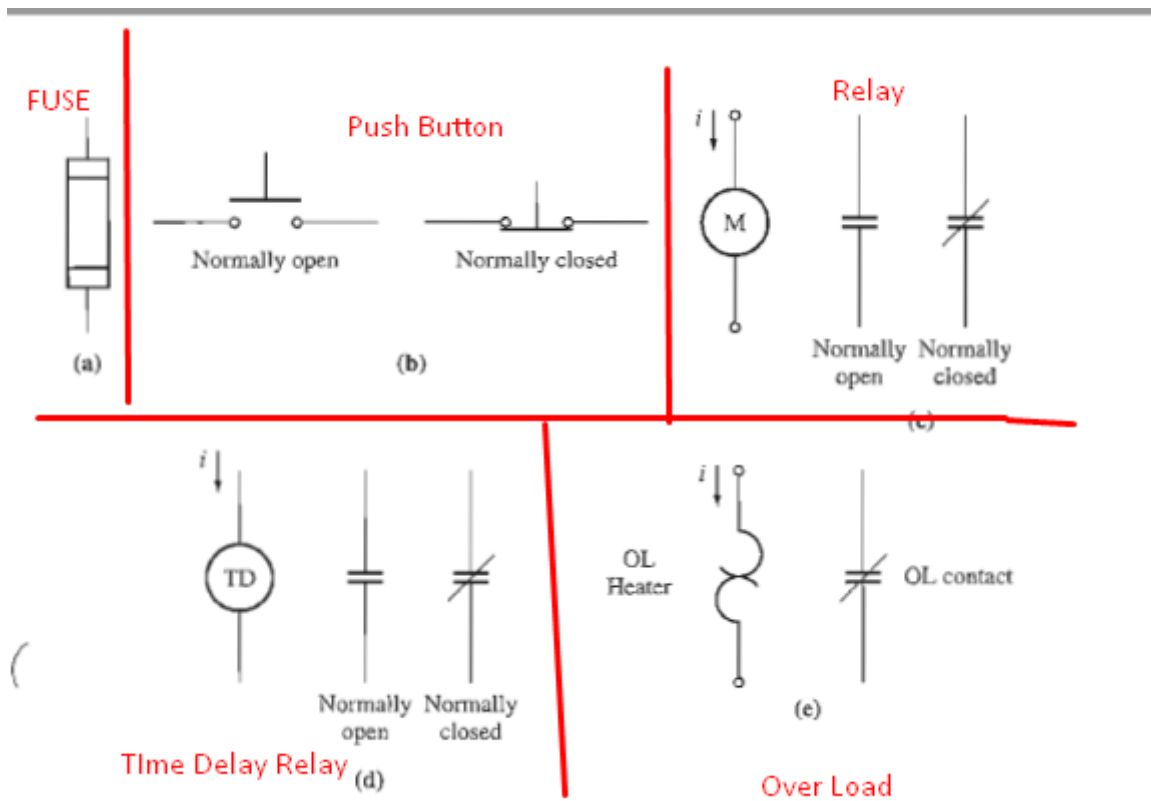
$$\frac{R_A}{R_{tot}} = \left(\frac{I_{min}}{I_{max}} \right)^n$$

$$n = \frac{\log (R_A/R_{tot})}{\log (I_{min}/I_{max})}$$

العدد ده لو طلع كسر بنقربه لاقرب رقم صحيح
ولانك بتقربه فلما التيار هيجي يزيد اخر مره بعد ما يكون متبقاش غير مقاومه الارميتشر هيرفع لتيار اقل من القيمه القصوى

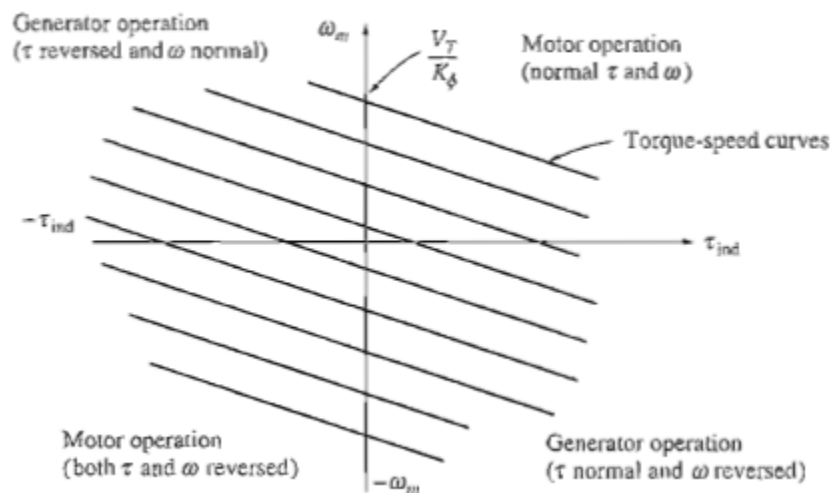
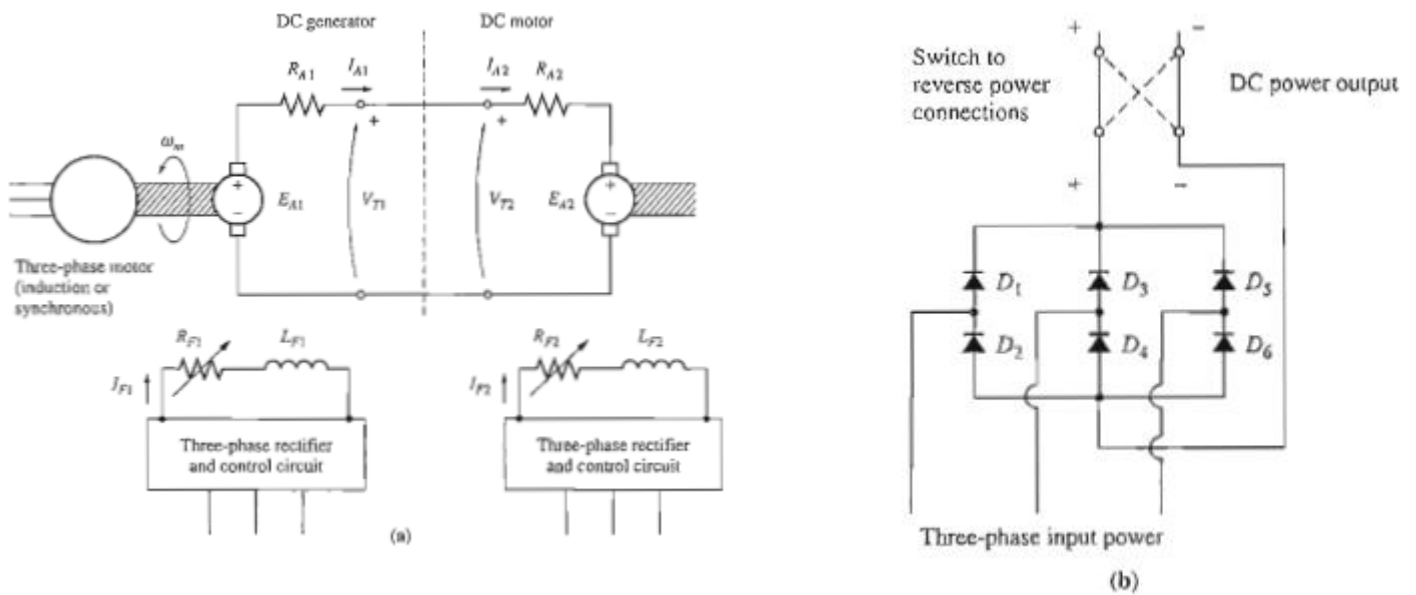


DC Motor Starting Circuits



The type on the right is better because : This type of starter is better than the previous one, since if [he motor is loaded heavily and starts more slowly than normal, its armature resistance is still cut out when its current falls to the proper value

The Ward-Leonard System



- it is possible to get a very wide range of speed variations in either direction of rotation out of a Ward-Leonard dc motor control system.

- it can "regenerate," or return the machine's energy of motion to the supply lines. If a heavy load is first raised and then lowered by the dc motor of a Ward-Leonard system, when the load is falling, the dc motor acts as a generator

When the motor is rotating in its normal direction and supplying a torque in the direction of rotation, it is operating in the first quadrant of this figure. If the generator's field current is reversed, that will reverse the terminal voltage of the generator, in turn reversing the motor's armature voltage. When the armature voltage reverses with the motor field current remaining unchanged, both the torque and the speed of the motor are reversed, and the machine is operating as a motor in the third quadrant of the diagram.

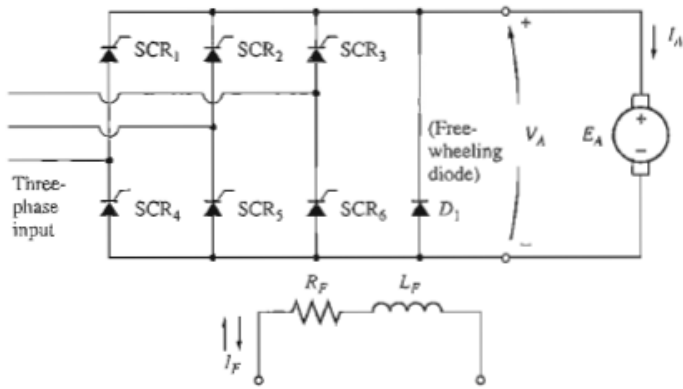
If the torque or the speed alone of the motor reverses while the other quantity does not, then the machine serves as a generator, returning power to the dc power system.

So it's a four-quadrant control system. Cuz : permits rotation and regeneration in either direction

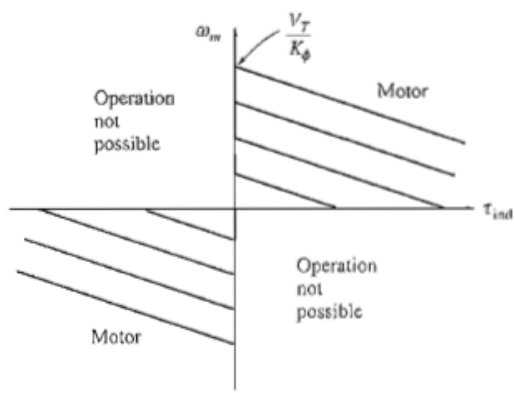
Disadvantages

- 1- is that the user is forced to buy three full machines of essentially equal ratings, which is quite expensive
- 2- is that three machines will be much less efficient than one

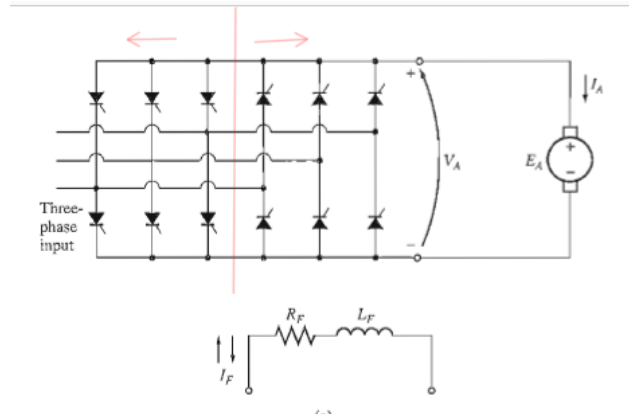
SOLID STATE CONTROLLER



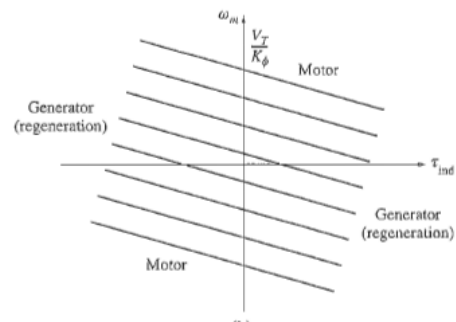
(a)



(b)



(a)



This particular circuit is only capable of supplying an armature voltage with one polarity, so the motor can only be reversed by switching the polarity of its field connection

cannot flow backward through a thyristor

two-quadrant

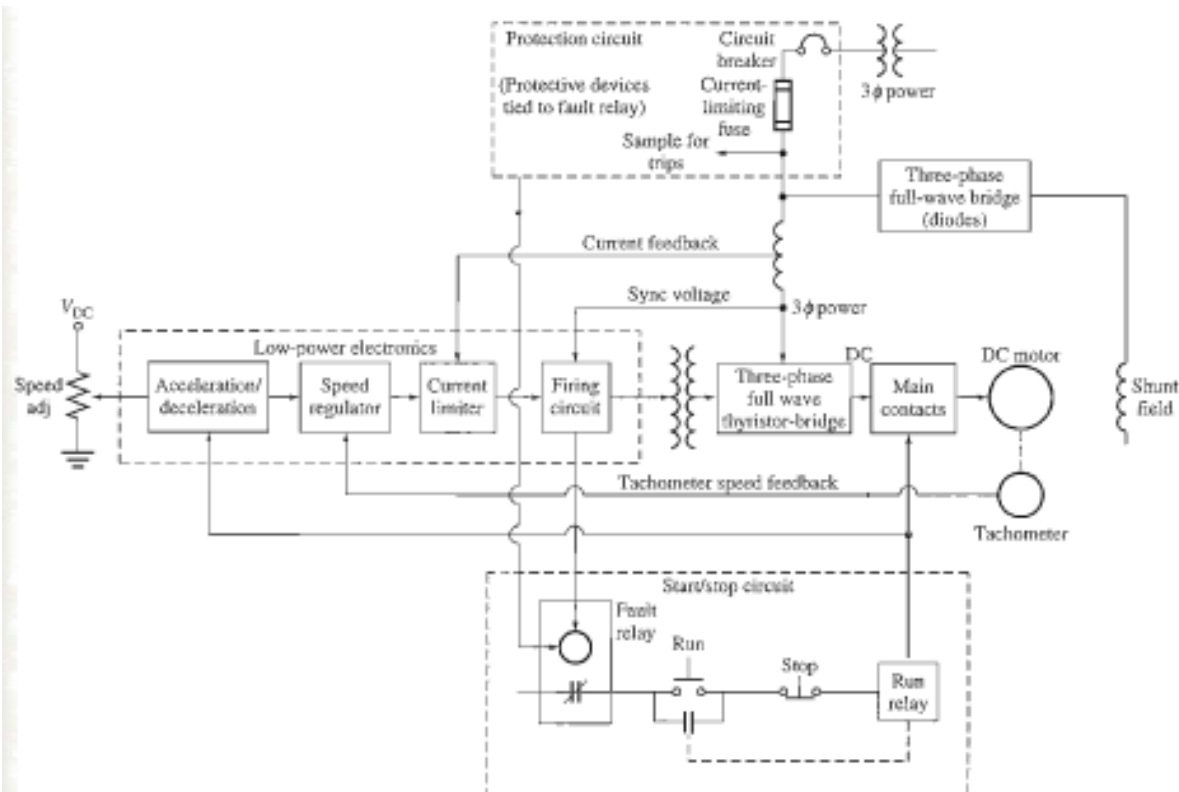
permit a current now out of the positive terminals of the generator, so a motor with this type of controller can regenerate. If the polarity of the motor field circuit can be switched as well,

four-quadrant

NOTE :

Since this motor controller has a **fixed field voltage** and a **variable armature voltage**, it is only able to control the speed of the motor **at speeds less than or equal to the base speed** (

DRIVER CIRCUIT



Sections :

1. **A protection circuit** section to protect the motor from excessive armature currents, low terminal voltage, and loss of field current.
2. **A start/stop** circuit to connect and disconnect the motor from the line.
3. **A high-power electronics** section to convert three-phase ac power to dc power for the motor's armature and field circuits.
4. **A low-power electronics** section to provide firing pulses to the thyristors which supply the armature voltage to the motor. This section contains several major subsections, which will be described below.

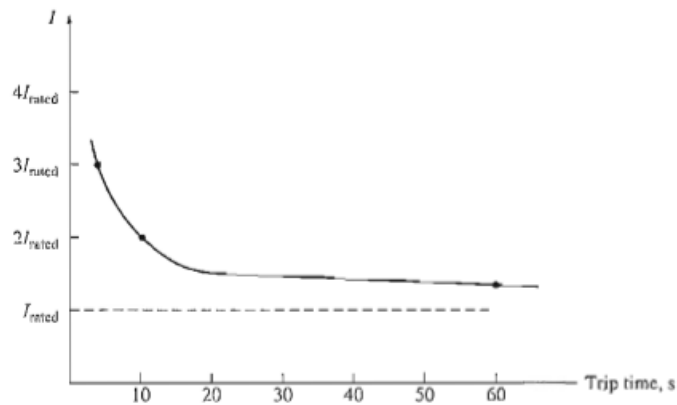
A) Protection Circuit

Current limiting fuses,	Disconnect when : short circuit within the motor
An instantaneous trip,	Disconnect when : the armature current exceeds 300 percent of its rated value.
An inverse-time overload trip,	If current not great enough to trigger the instantaneous static trip but large enough to damage the motor

	Inverse time : the higher the overcurrent flowing in the motor, the faster the overload acts
An undervoltage trip	Disconnect when : line voltage drops by more than 20 percent.
A field loss trip,	Disconnects when : field circuit is lost
An overtemperature trip,	Disconnect when : overheating.

B) Start/Stop Circuit Section

start/stop circuit section contains the controls needed to start and stop the motor by opening or closing the main contacts connecting the motor to the line. The motor



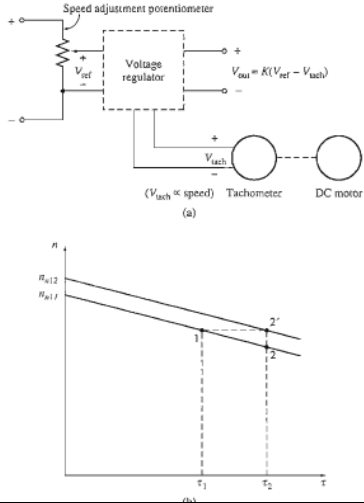
Stop 1- stop button 2- energizing the fault relay

C) High-Power Electronics Section

- 1- three-phase full-wave **diode** rectifier to provide a **constant** voltage to the **field circuit**
- 2- full-wave **thyristor** rectifier to provide a **variable** voltage to the **armature circuit**

D) Low-Power Electronics Section

Speed regulation circuit.	- increases or decreases the armature voltage as necessary to keep the speed constant at the desired value - can provide speed regulations of 0.1 percent between no-load and full-load conditions
---------------------------	---

	 The diagram (a) shows a speed adjustment potentiometer connected to a voltage regulator. The voltage regulator's output is $V_{out} = K(V_{ref} - V_{tach})$, which is applied to the armature of a DC motor. A tachometer is connected to the motor's shaft, providing a feedback voltage V_{tach} proportional to speed. Below the circuit is a graph of speed n versus torque τ. It shows two parallel, downward-sloping lines representing the motor's speed-torque characteristics. The first line has intercepts n_{s1} and n_{s1} on the y-axis. The second line, shifted upwards, has intercepts n_{s2} and n_{s2} on the y-axis. Points 1 and 2 are marked on the first line at torque levels τ_1 and τ_2 respectively. Points 1' and 2' are marked on the second line at the same torque levels. The vertical distance between the lines represents the speed increase achieved by the feedback control.
Current-limiting circuit.	-decreases the armature voltage as necessary to keep the current from exceeding the desired maximum - wide range, say from 0 to 200 percent - set at greater than rated current, so that the motor can accelerate under full -load conditions.
Acceleration/deceleration circuit.	- Whenever a dramatic speed change is commanded, this circuit intervenes to ensure that the transition from the original speed to the new speed is smooth and does not cause an excessive armature current transient in the motor - The acceleration/deceleration circuit completely eliminates the need for a starting resistor,

DC Motor Efficiency

- 1- Copper losses
2. Brush drop losses
3. Mechanical losses
4. Core losses
5. Stray losses

Copper losses calculations not accurate cuz :

1. The cooling that normally occurs when the motor is spinning will not be present.
2. Since there is an ac voltage in the rotor conductors during normal operation, they suffer from some amount of skin effect, which further raises armature resistance.

Brush drop losses from a plot of contact potential versus current for the particular type of brush being used $P_{Brush} = V_{BD} I_A$

Steps:

- 1- We connect a voltage supply to the DC motor (shunt)
- 2- We connect the shaft of the DC motor to an eddy-current brake machine
- 3- The eddy-current brake works as a variable load that when the conductors of it's rotor rotates an eddy current is induced by an electromagnet.

Objectives :

- 1- Calculating the efficiency (η)
- 2- Relation Between T_L and ω_m
- 3- Relation between I_{in} and η
- 4- Calculate the iron losses and stray losses

From the experiment we got the following results :

$$R_f = 555 \Omega ; R_A = 3.6 \Omega$$

$$P_i = P_0 + P_{iron} + P_{nl} + P_{stray}$$

$$P_i = I_{in} V_{in} ; P_0 = T * \omega ; \eta = \frac{P_o}{P_{in}} ; I_f = \frac{V_{in}}{R_f} ; I_a = I_{in} - I_f$$

DC GENERATORS

Types :

1. **Separately** excited generator. In a separately excited generator, the field flux is derived from a separate power source independent of the generator itself.
2. **Shunt** generator. In a shunt generator, the field flux is derived by connecting the field circuit directly across the terminals of the generator.
3. **Series** generator. In a series generator, the field flux is produced by connecting the field circuit in series with the armature of the generator.
4. **Cumulatively** compounded generator. In a cumulatively compounded generator, both a shunt and a series field are present, and their effects are additive.
5. **Differentially** compounded generator. In a differentially compounded generator, both a shunt and a series field are present, but their effects are subtractive.

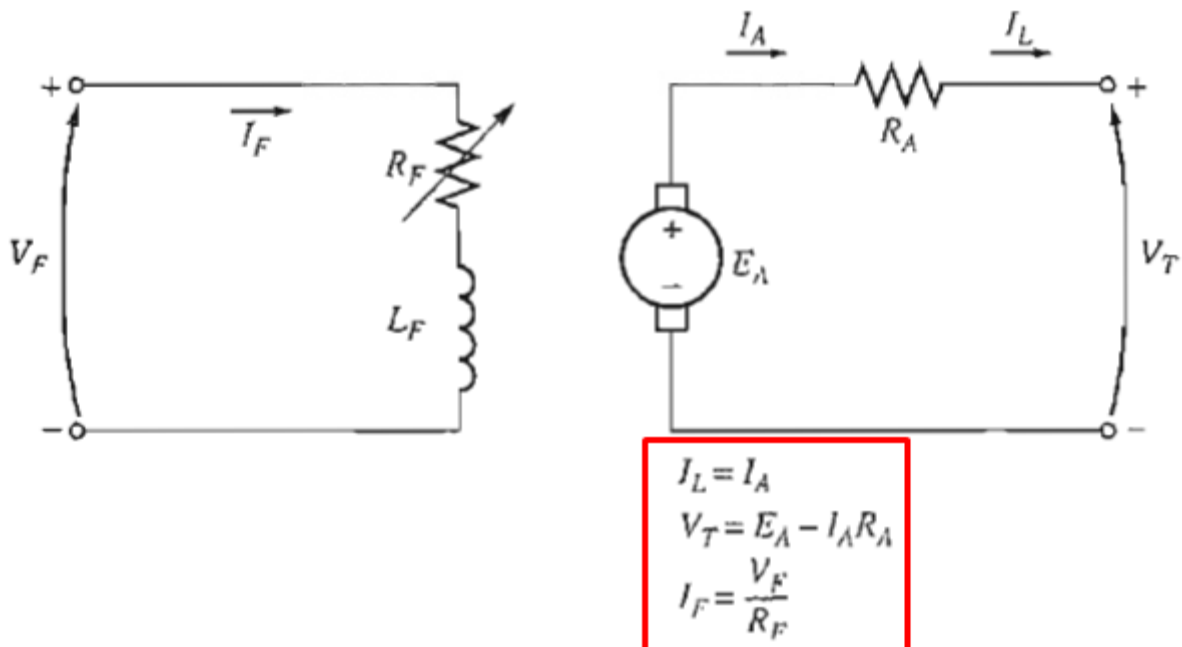
Regulation

+ve : dropping ch/c

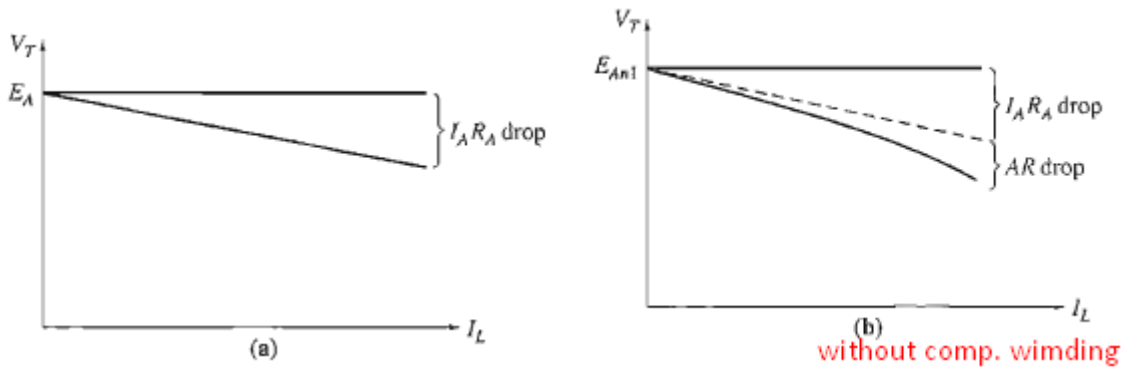
$$VR = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

-ve : rising ch/c

SEPERATELY EXCITED DC GENERATOR



Terminal Ch/c



Control of output Voltage

1. Change the speed of rotation. If ω increases, then $E_A = k \phi \omega_m \uparrow$ increases, so

$V_T = E_A \uparrow - I_A R_A$ increases as well.

2. Change the field current. If R_F is decreased, then the field current increases ($I_F = \frac{V_F}{R_F \downarrow}$). Therefore, the flux ϕ , in the machine increases. As the flux rises, $E_A = k \phi \uparrow \omega_m$ must rise too, so $V_T = E_A \uparrow - I_A R_A$ increases. (Most Common method)

Nonlinear Analysis

To determine the output voltage in a machine with armature reaction is to use graphical analysis.

$$\mathcal{F}_{\text{net}} = N_F I_F - \mathcal{F}_{\text{AR}} \quad \rightarrow \quad I_F^* = I_F - \frac{\mathcal{F}_{\text{AR}}}{N_F} \quad \rightarrow \quad \frac{E_A}{E_{A0}} = \frac{n_m}{n_0}$$

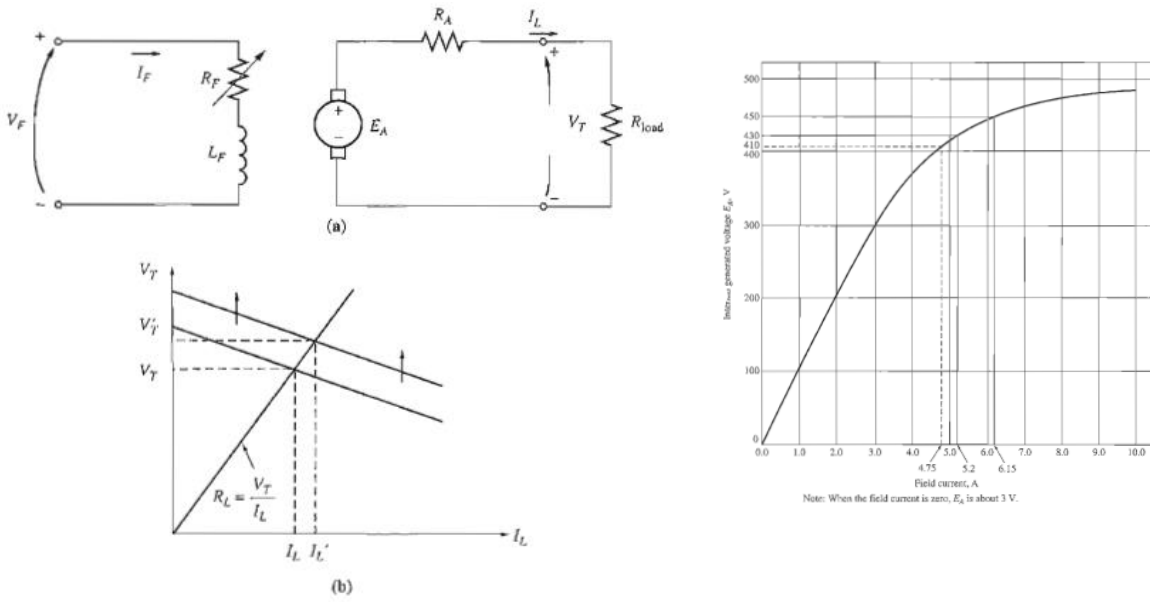
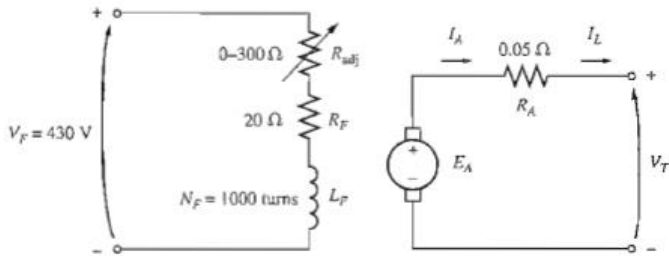
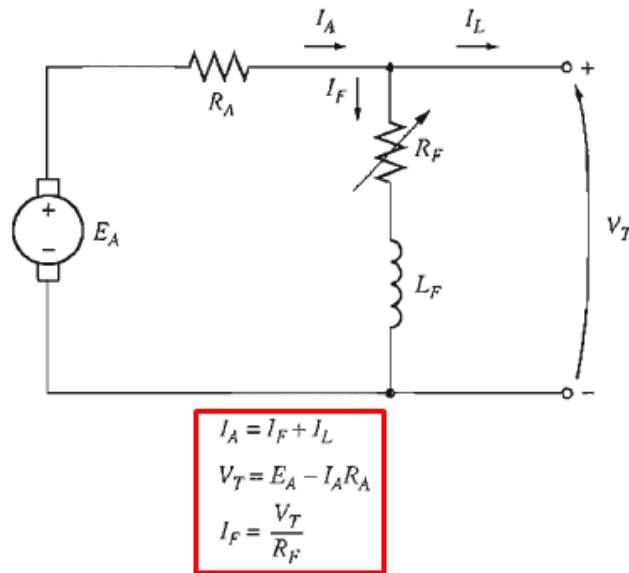


FIGURE 8-46
 (a) A separately excited dc generator with a resistive load. (b) The effect of a decrease in field resistance on the output voltage of the generator.



SHUNT DC GENERATOR



advantage over the separately excited generator in that no external power supply is required for Field

Voltage Buildup in a Shunt Generator

-depends on the presence of a residual flux

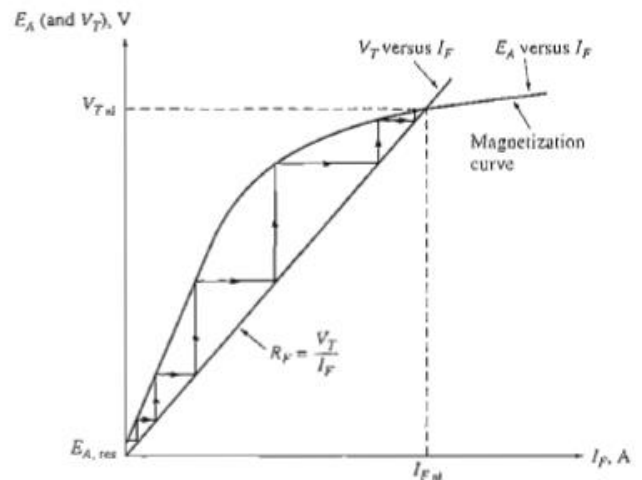
$$E_A = K \phi_{\text{res}} \omega_m$$

-causes a current to flow in the generator's field coil

$$(I_F = V_T / R_F)$$

-produces a magnetomotive force in the poles. which increases the flux in them

-causes an increase in $E_A = K \phi \omega_m$, which increases the terminal voltage V_T . When V_T rises, I_F increases further, increasing the flux ϕ more, which increases E_A . etc.



Note : In a real generator, the voltage does not build up in discrete steps:

Causes not to build up voltage :

1. There may be no residual magnetic flux solution “ **Flashing the field** : disconnect the field from the armature circuit and connect it directly to an external dc source
2. The direction of rotation of the generator may have been reversed,
3. the connections of the field may have been reversed

2,3 : **problem** : flux opposing the residual flux , **solution** : by reversing the field connections, or by flashing the field

4. The field resistance may be adjusted to a value greater than the critical resistance.

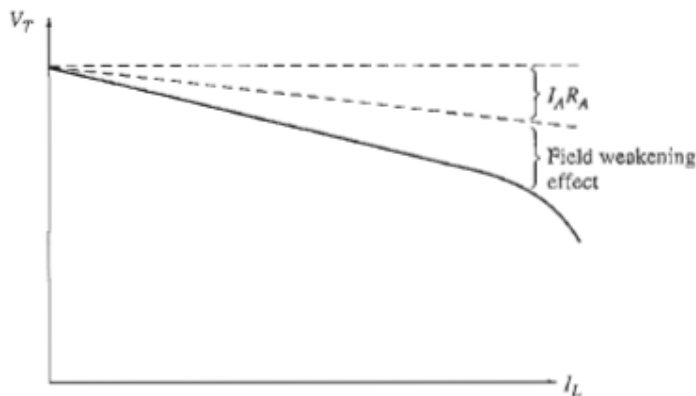
Solution : The solution to this problem is to reduce R_f

Note : Since the voltage of the magnetization curve varies as a function of shaft speed, the critical resistance also varies with speed. In general, **the lower the shaft speed, the lower the critical resistance.**

The Terminal Characteristic of a Shunt DC Generator

the amount of field current in the machine depends on its terminal Voltage.

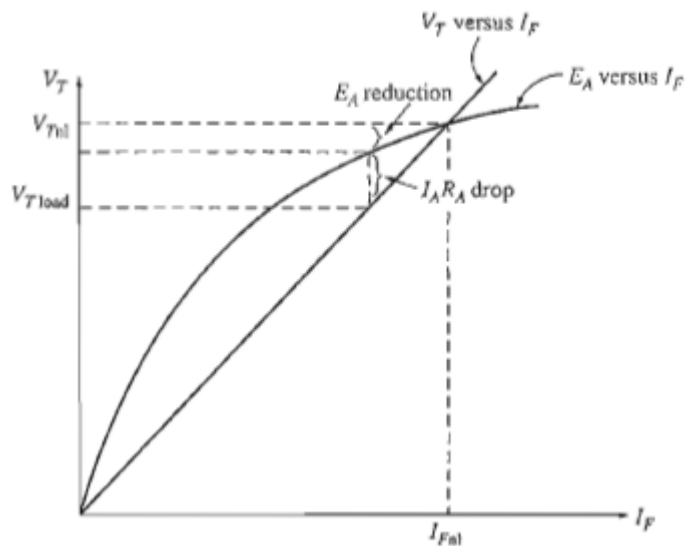
the **voltage regulation** of this generator is **worse** than the voltage regulation of the same piece of equipment connected **separately** excited.



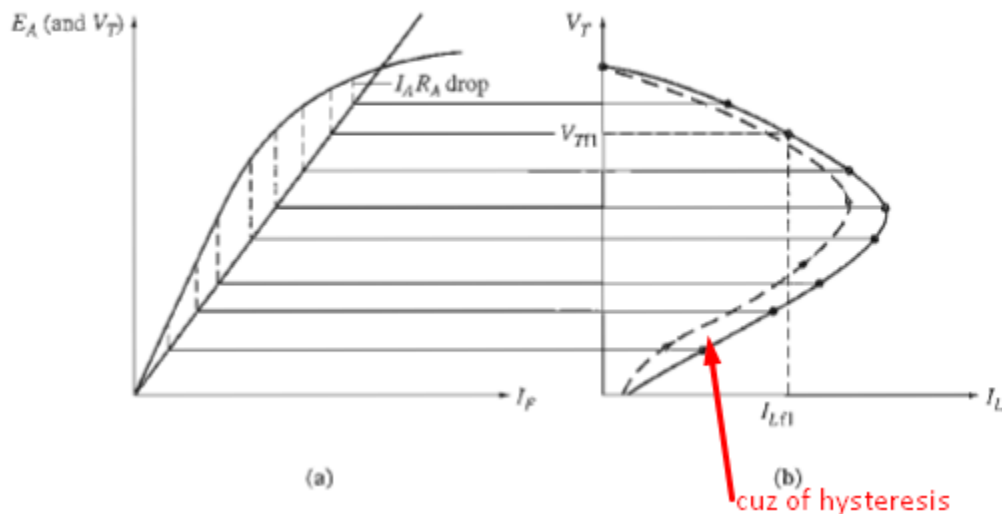
Voltage Control for a Shunt DC Generator

1. Change the shaft speed ω_m of the generator.
2. Change the field resistor of the generator, thus changing the field current I_F . (principal method)

The Analysis of Shunt DC Generators



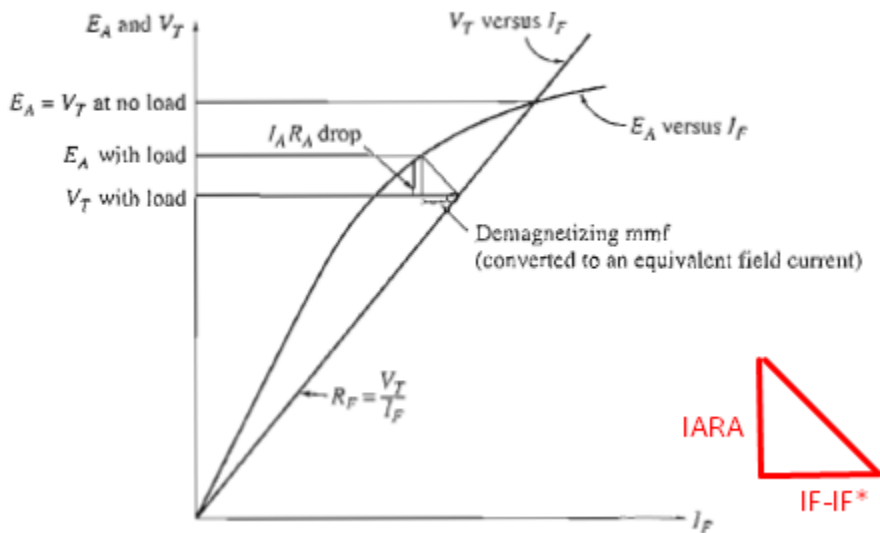
If there are two possible positions, the one nearer the no-load voltage will represent a normal operating point



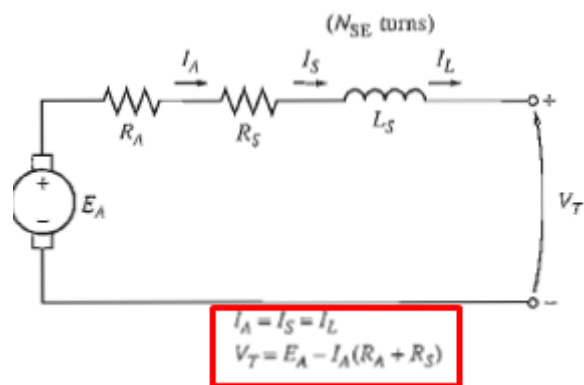
The reason that it

does not coincide with the line of increasing load is the hysteresis in the stator poles of the generator.

With armature reaction

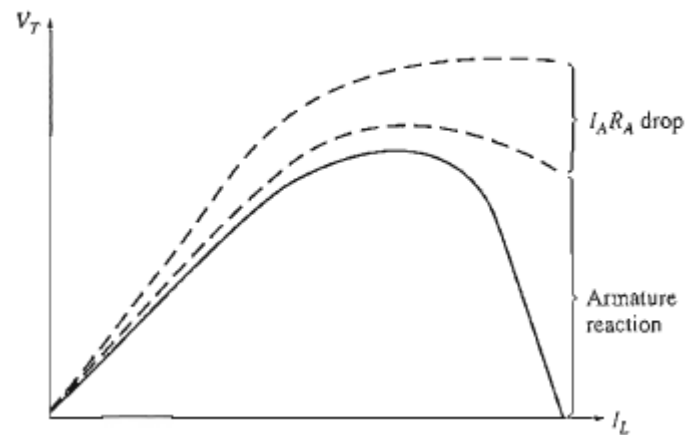
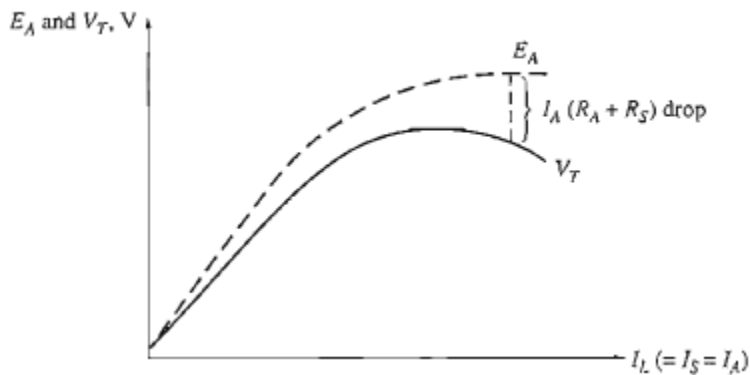


THE SERIES DC GENERATOR



Field will have less turns and be more thick to withstand higher current as $\mathcal{F} = NI$,

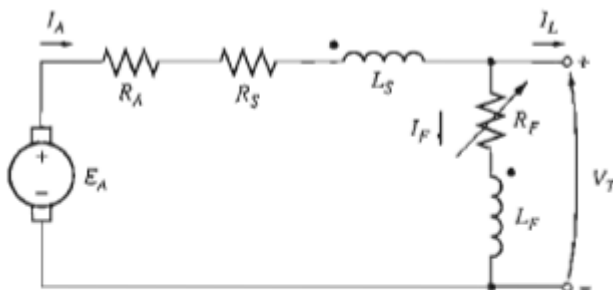
The Terminal Characteristic of a Series Generator



- bad constant-voltage source
- voltage regulation is a large negative number

Application : arc welding : very large current flows. As the operator separates the welding electrodes, there is a very steep rise in the generator's voltage while the current remains high. This voltage ensures that a welding arc is maintained through the air between the electrodes.

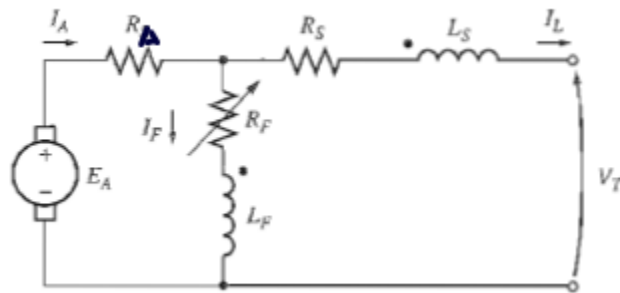
THE CUMULATIVELY COMPOUNDED DC GENERATOR



$$\begin{aligned}
 I_A &= I_L + I_F \\
 V_T &= E_A - I_A(R_A + R_S) \\
 I_F &= \frac{V_T}{R_F} \\
 \mathcal{F}_{\text{net}} &= N_F I_F + N_{SE} I_A - \mathcal{F}_{AR}
 \end{aligned}$$

$$N_F I_F^* = N_F I_F + N_{SE} I_A - \mathcal{F}_{AR}$$

$$I_F^* = I_F + \frac{N_{SE}}{N_F} I_A - \frac{\mathcal{F}_{AR}}{N_F}$$

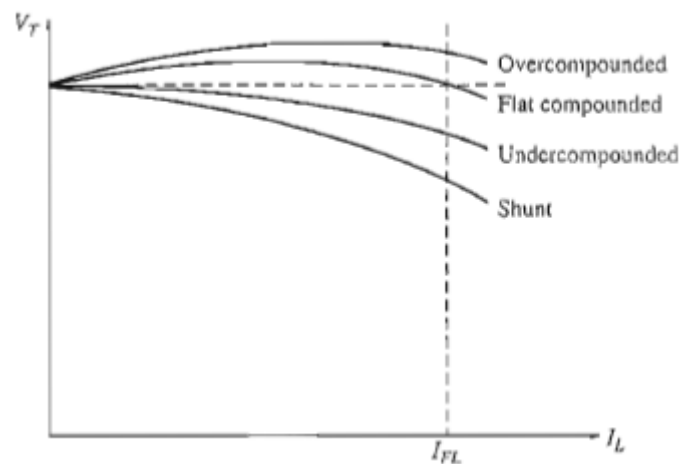


The Terminal Characteristic of a Cnmulatively Compounded DC Generator

two effects occur in the generator as I_A increase

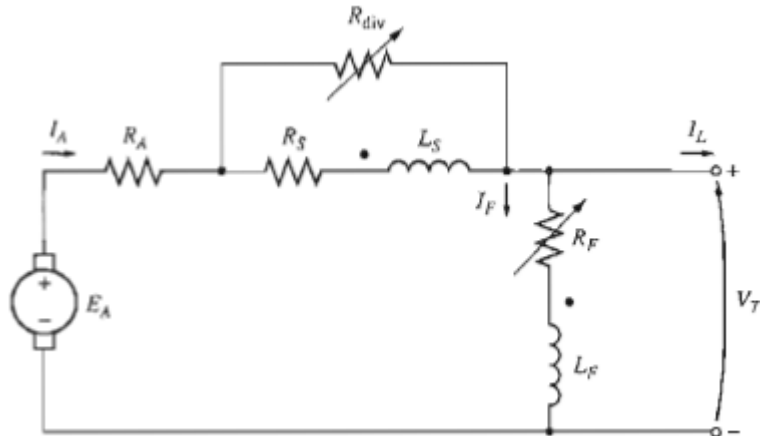
- 1- $I_A(R_A + R_S)$ voltage drop increases , This tends to cause a **decrease** in the terminal voltage
 $V_T = E_A - I_A(R_A + R_S)$.
- 2- the series field magnetomotive force increase $\mathcal{F}_{tot} = N_F I_F + N_{SE} I_A \uparrow$ will **increase** terminal voltage $V_T = E_A \uparrow - I_A(R_A + R_S)$ rise.

this will result to 3 kinds of ch/c



- 1- under-compounded : N_{SE} small : full-load terminal voltage is less than the no-load
- 2- flat-compounded : N_{SE} large : no load is equal to V_r at full load,
- 3- over-compounded : N_{SE} larger : full -load terminal voltage actually higher than the no-load terminal voltage.

We use a diverter resistor to control the amount of compounding needed



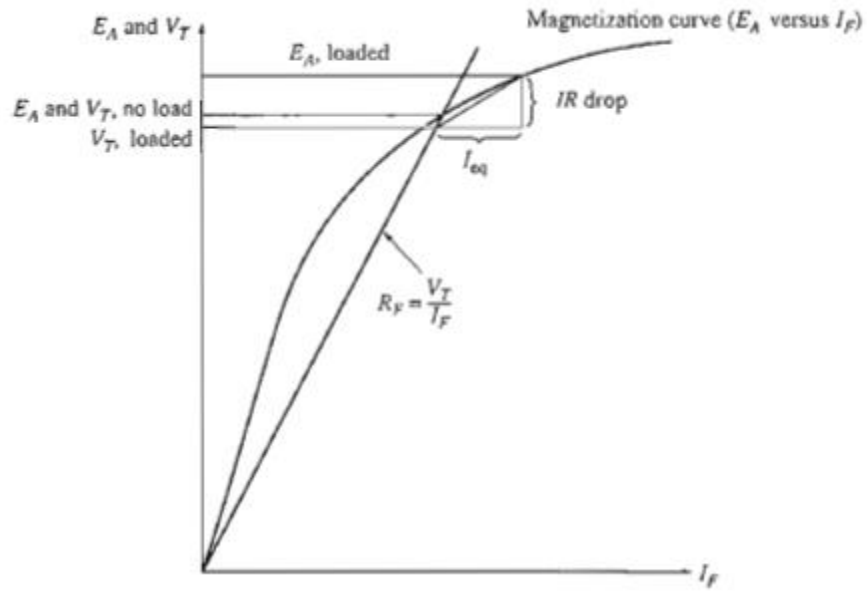
Voltage Control of Cumulatively Compounded DC Generators

1. **Change the speed of rotation.** An increase in ω causes $E_A = K\phi\omega_m \uparrow$ to increase, increasing the terminal voltage $V_T = E_A \uparrow - I_A(R_A + R_S)$.
2. **Change the field current.** A decrease in R_F causes $I_F = V_T/R_F \downarrow$ to increase, which increases the total magnetomotive force in the generator. As $\mathcal{F}_{tot}$ increases, the flux ϕ in the machine increases, and $E_A = K\phi\omega_m$ increases. Finally, an increase in E_A raises V_T .

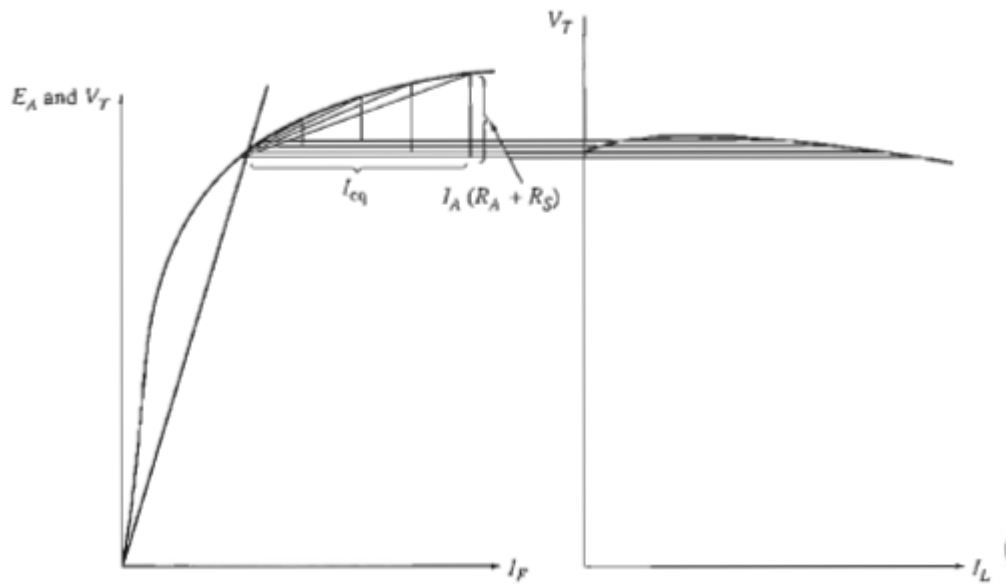
Analysis of Cumulatively Compounded DC Generators

$$I_{eq} = \frac{N_{SE}}{N_F} I_A - \frac{\mathcal{F}_{AR}}{N_F}$$

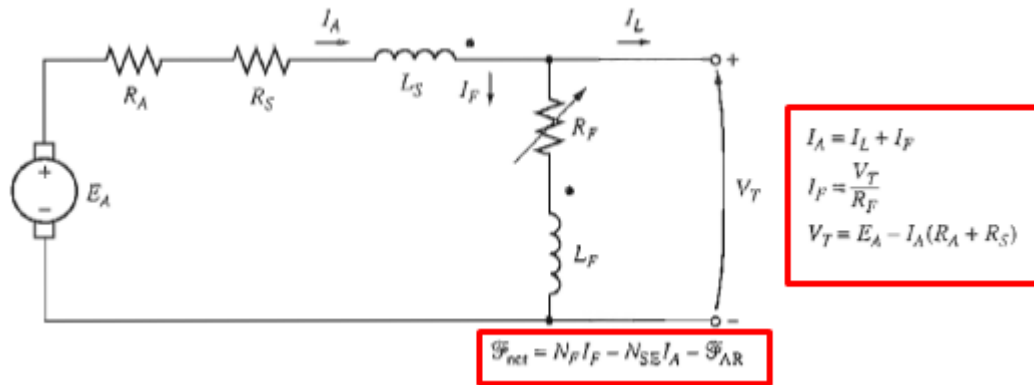
$$I_F^* = I_F + I_{eq}$$



As load is added to the generator, the series field magnetomotive force increases, increasing I_{eq} & $I_A(R_A + R_S)$



THE DIFFERENTIALLY COMPOUNDED DC GENERATOR



$$\Phi_{\text{net}} = \Phi_F - \Phi_{SE} - \Phi_{AR}$$

$$\Phi_{\text{net}} = N_F I_F - N_{SE} I_A - \Phi_{AR}$$

$$I_{cq} = -\frac{N_{SE}}{N_F} I_A - \frac{\Phi_{AR}}{N_F}$$

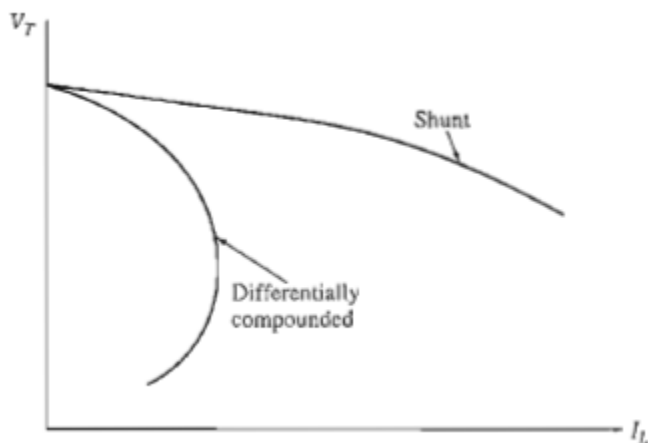
$$I_F^* = I_F - \frac{N_{SE}}{N_F} I_A - \frac{\Phi_{AR}}{N_F}$$

The Terminal Characteristic of a Differentially Compounded DC Generator

As I_A increase

- 1- $I_A(R_A + R_S)$ voltage drop increases, will **decrease** terminal voltage $V_T = E_A - I_A(R_A + R_S)$.
- 2- series mmf increase ($\Phi_{\text{net}} = N_F I_F - N_{SE} I_A \uparrow$) will **decrease** terminal voltage V_T

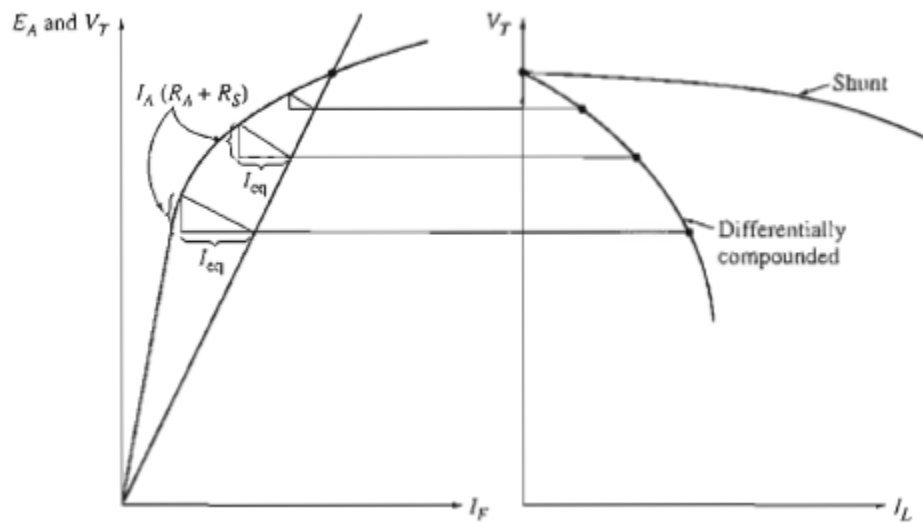
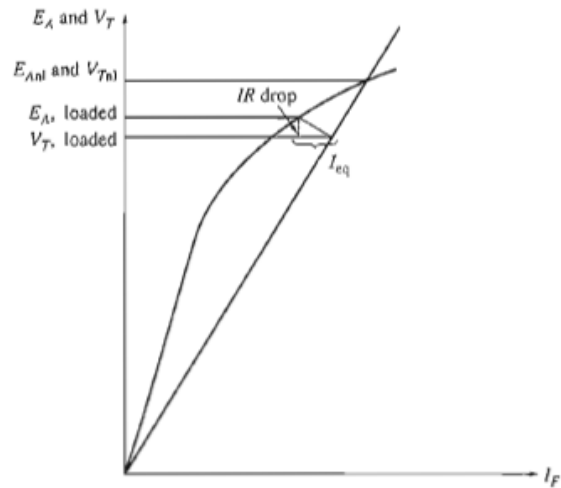
the voltage drops drastically as the load is increased on the generator



Voltage Control of Differentially Compounded DC Generators

1. Change the speed of rotation ω_m
2. Change the field current I_F

Graphical Analysis of a Differentially Compounded DC Generator



nonlinear effects are at the heart of the generator's operation,

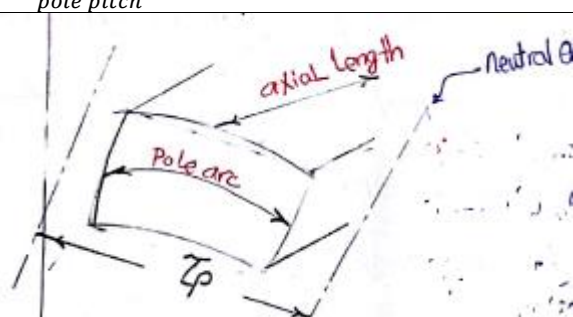
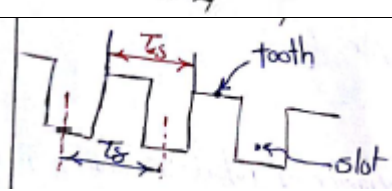
DESIGN

Content :

- 1- Field System Design (Magnetic Pole)
- 2- Armature Design
- 3- Magnetic Circuit
- 4- Design range
- 5- Commutator, Compensating winding and interpoles design

Abbreviations

الرمز	الإختصار
Field System Design (Magnet Pole)	
$A.T$	Ampere turn or mmf of field winding
d_e	Current density in the field winding
h_e	Height of field winding
b	Depth of field winding
L_e	Mean length of turn
R_F	Resistance of field coil
N_F	Number of turns of field coil
a_F	Area of each conductor / bare cross section area
$2L_e h_e$	Area of heat dissipation
P_e	Permissible copper losses per unit area
P_F	Copper losses of field coil $I_F^2 R_F$
F_e	Space factor & backing factor
ρ	Resistivity of the material
$\frac{h_e}{d_0}$	Number of turns per layer
$N(\frac{h_e}{d_0})$	Number of layers
I_F	Field Current
Armature Design	
D	Diameter of rotor cylinder
L	Length of rotor cylinder
L_i	Net iron length
e_{ind}	Mmf induced at the rotor terminals
ϕ	Useful flux
B	Average flux density (Specific magnetic loading)
B_g	Max. of flux density
$2P$	Total number of poles

ac	Specific electric loading
$2a$	Total number of parallel paths
Z	Total number of conductors
Z_s	Total number of conductors per slot
U	Number of coil sides per slot
T_c or N_c	Number of turn per coil
P_d	Armature developed power
I_a	Armature current
I_c	Conductor current
ω_m	Angular velocity
n	Speed in rpm
α	The ratio $\frac{\text{axial length}}{\text{pole arc}}$
β	The ratio of $\frac{(\text{pole arc})}{\text{pole pitch}}$
τ_p	The distance between two neutral axis 
τ_s	the distance between a tooth and it's following 
C_0	Power co-efficient
$\frac{S}{2P}$	Number of slots per pole
y_c	Commutator pitch
y_B	Back pitch
y_f	Forward pitch

Relations :

Field System Design (Magnet Pole)

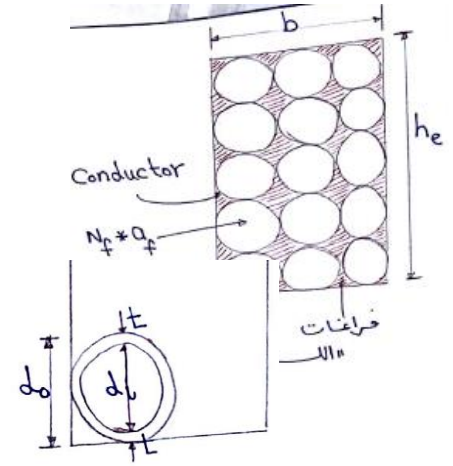
SUMMARY :

$$R = \frac{V}{I} = \frac{\rho l_e N_F}{a_f} \quad (\text{Resistance of field})$$

$$a_F = \frac{\rho L_e N_F}{R_F} \quad (\text{area of field winding})$$

$$d_e = \sqrt{\frac{2P_e}{\rho b F_e}} \quad (\text{Current density in field winding})$$

$$I_F = d_e * a_f = \sqrt{\frac{P_F}{R_F}} \quad (\text{Field Current})$$



Stacking Factor		
Without insulation	With insulation	General
$F_e = \frac{\pi}{4}$	$F_e = \frac{\pi}{4} * \frac{d_{in}^2}{d_0^2}$	$F_e = \frac{a_F * N_F}{h_e * b}$

$\text{no of turns per layer} = \frac{h_e}{d_0}$	$\text{no of layer} = \frac{\text{no of turns}}{\text{no of turns per layer}} = \frac{N_F}{\frac{h_e}{d_0}}$
--	--

Number of conductors per coil side = number of coil turns

P_F (copper Loss of field coil)	
$2 * L_e * h_e * P_e$	$(d_e)^2 * a_f * L_e * \rho * N_F$

Ampere turn	
general	At max AT
$AT = h_e \sqrt{\frac{2 P_e * b * F_e}{\rho}}$	$N_F a_F = b * h_e * f_e$

$$\frac{AT}{h_e} = \sqrt{\left(\frac{2P_e b f_e}{\rho}\right)} h_e = \frac{AT}{\left(\frac{AT}{h_e}\right)}$$

ARMATURE DESIGN

To design any motor we know the (Power – Voltage – Speed) required

$$E_A = K' \phi n \Rightarrow K' = \frac{2P * Z}{2a * 60}$$

$$\phi = BA = B \tau_p L = B \left(\frac{\pi D}{2P} \right) L$$

$$\therefore E_A = \frac{2P}{2a} \phi Z \frac{n}{60} = \frac{Z}{2a * 60} B (\pi D) L n$$

$$\therefore \frac{P_a}{n} = C_0 D^2 L$$

$$C_0 = 0.164 * 10^{-3} * B * ac \text{ (Power coefficient)}$$

$$\alpha \beta = \frac{\text{axial length}}{\text{pole pitch}} = \frac{l}{\tau_p} = \frac{2PL}{\pi D}$$

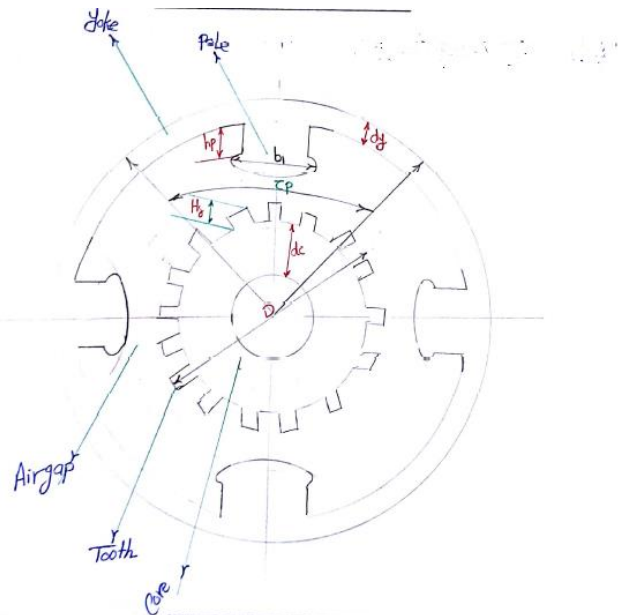
Design معادلات ال	
$\frac{P_a}{n} = C_0 D^2 L$	$\alpha \beta = \frac{2PL}{\pi D}$
$E = \frac{Z}{2a} B l V_a$	

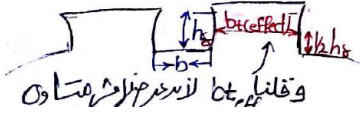
MAGNETIC CIRCUIT

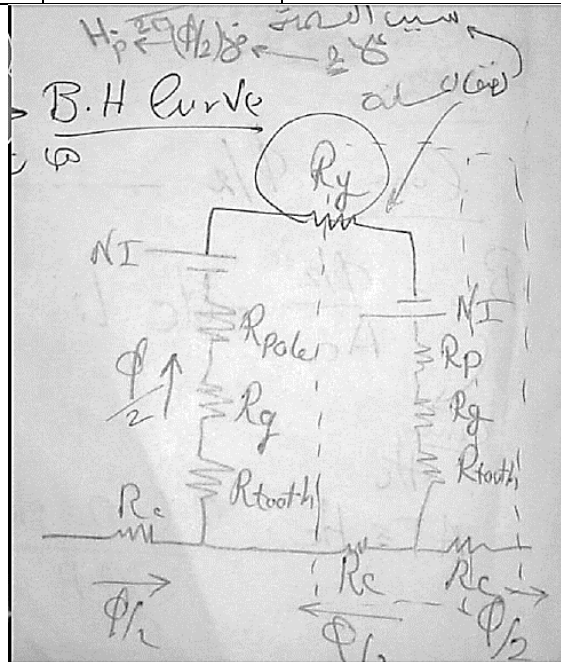
Field paths

- 1- Yoke
- 2- Pole
- 3- Air gap
- 4- Teeth
- 5- Core

We get $\phi \rightarrow B \rightarrow H \rightarrow \rightarrow AT = H * l$



Yoke	Pole	Air gap	Teeth	Core
$A_y = d_y * L_i$ $B_y = \frac{\phi}{2A_y}$ <i>from table H_y</i> L_y $= \frac{\pi(D + 2h_p + d_y)}{2(2P)}$ $A.T = H_y * L_y$	 $\phi_{leakage}$ ϕ_{useful} $\phi_p = K_{LP}(=1) * \phi$ $A_p = \tau_p * L_i = b_p * L_p$ $B_p = \frac{\phi_p}{A_p}$ $\rightarrow H_p$ $A.T = H_p * h_p$	$A_g = \tau_p * L_i$ $B_{gp} = \frac{\phi * k_g}{\alpha * A_g}$ $H_g = \frac{B_{gp}}{\mu_0}$ $\mu_0 = 4\pi * 10^{-7}$ $A.T = H_g * L_g$	 b_{teff} $B = \frac{\phi}{A}$ $b_{teff} = \frac{\pi(D - \frac{4}{3}h_s)}{S} - bs$ $B_{app} = \frac{\phi}{(K_f(=\alpha) * \frac{S}{2P} * b_{teff} * L_i)}$ H_{teeth} $A.T = H_{teeth} * h_s$	$d_c = \frac{1}{2}(D - D_{in} - 2h_s)$ $A_{core} = d_c * L_i$ $B_{core} = \frac{\phi}{A_{core}}$ $\rightarrow H_{core}$ L_c $= \frac{\pi(D - 2h_s - d_c)}{2(2p)}$ $A.T = H_c * L_c$



$$stacking\ factor = \frac{li}{l}$$

Iron Losses

teeth	core
$\text{eddy} = A(B_t f t)^2 \left(\frac{\text{watt}}{\text{kg}} \right)$ $f = \frac{pn}{60}$ $B, f \xrightarrow{\text{from curve}} H$ $V_t = b_{t_{eff}} * L_i * h_t * s$ $m_t = \rho * v_t (\text{kg})$ $\text{loss} = (\text{eddy} + \text{hyst}) * m_t$	$\text{eddy} = A (B_c f t)^2$ $f = \frac{pn}{60}$ $B, f \xrightarrow{\text{from curve}} H$ $V_c = \pi (D - 2h_s - dc) * d_c * l_i$ $m_c = \rho * v_c$ $\text{loss} = (\text{eddy} + \text{hyst}) * m_c$

$$I_{\text{ironloss}} = P_t + P_c$$

$$\underline{c)} \quad \theta_c = C \frac{P_{\text{arm}}}{S}$$

$$P_{\text{arm}} = Cu_{\text{loss}} + \text{Iron loss}$$

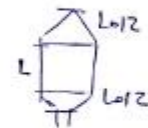
$$= I_a^2 R_a + \text{Iron loss}$$

$$= (800)^2 * 0.0114 + 2594 = 9890 \text{ W}$$

$$S = \pi D (L + L_o) = \pi D \left(\frac{L_i}{k_s} + L_o \right)$$

$$= \pi * 72 * \left(\frac{26.5}{0.95} + 14.5 \right)$$

$$= 9589.5 \text{ cm}^2$$



$$C = \frac{300}{1 + 0.09 v_a^{1.3}} ; \quad v_a = \frac{\pi D n}{60} = \frac{\pi * 0.72 * 600}{60} = 22.6 \text{ m/s}$$

$$= \frac{300}{1 + 0.09 (22.6)^{1.3}} = 48.52 \text{ } ^\circ\text{C} \cdot \text{cm}^2/\text{W} \quad \left[\begin{array}{l} \text{if } 300 \\ \rightarrow 0.03 \\ \text{then } ^\circ\text{C} \cdot \text{m}^2/\text{W} \end{array} \right]$$

$$\theta_c = 48.52 * \frac{9890}{9589.5}$$

$$= 50.04^\circ\text{C}$$



Where $AT = AT_p + AT_g + AT_t + AT_c + AT_y$
 and $E_2 = E_1 \times \frac{\phi_2}{\phi_1}$ at $w = \text{constant}$ as $E = k \phi w$

we obtain :

ϕ	0.0697	1.1 ϕ	0.8 ϕ	0.6 ϕ	0.4 ϕ
AT	6792.68	12245.135	3936.28	2737.24	1800.95
E	500	550	400	300	200

The design limitations are :

$$v_A \leq 20 \text{ m/s}, \quad \tau_c \geq 4 \text{ mm}, \quad I_{\text{brush}} \leq 70 \text{ A},$$

$$\theta_c \leq 40^\circ \text{C}, \quad s = 6 \text{ A/cm}^2$$

Also: Brush $\xrightarrow{\text{Covers}}$ 3 segments

$$V.D._{\text{brush}} = 1.5 \text{ V}$$

$$\mu = 0.15$$

$$P_B = 20 \text{ kN/m}^2$$

$$C = \frac{0.012}{1 + 0.1 v_c}$$

$$D_c = (0.6 : 0.8) \text{ D}$$

Commutator

No Commutator segments = No of coils

$$V_c = r\omega = \frac{\pi D n}{60} \quad V_c \leq 20$$

$$V_c = \frac{\pi D_c}{\text{no of commutator segments}}$$

$$\tau_c (\text{commutator pitch}) \geq 4 \text{ mm}$$

$$D_c (\text{commutator diameter}) = (0.6 : 0.8) D$$

$$L_c = n_b * (W_b + bc_{\text{brush clearance}}) + C_1 + C_2$$

$$\text{assume } b_c = 5 \text{ mm}, C_1 = C_2 = 20 \text{ mm}$$

$$L_c (\text{with risers}) = L_c + 50 \text{ mm}$$

$$S_c (\text{commutator Area}) = \pi D_c L_c$$

Brushes

$$I_a = \frac{P_a}{V_A}$$

$$I_{\text{spindle}} = \frac{I_a}{P}$$

$$n_b (\text{number of brushes}) = \frac{I_{\text{spindle}}}{70}$$

$$\delta_b = 6 \frac{A}{\text{cm}^2}, \quad a_b = \frac{I_b}{\delta}$$

$$V_{BD} = 1.5 \text{ V}$$

Total losses in brush $P_b = P_c + P_{BF} \left(\frac{\text{KN}}{\text{m}^2} \right)$	
Brush contact drop	Brush friction losses
$P_c = V_{BD} * I_A$	$P_{BF} = \mu P_b * 2P * A_b (\text{of spindle}) * V_c$ $\mu = 0.15 \quad P_b = 20000 \text{ N/m}^2$

$$t_b (\text{brush thickness}) = \frac{n_b}{\tau_c} > 4\text{mm}$$

$$W_b (\text{brush width}) = \frac{a_b}{t_b}$$

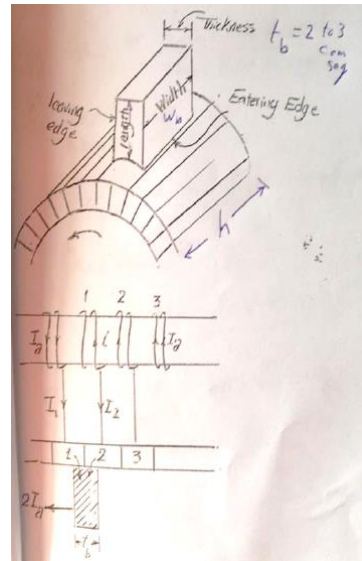
$$S_{\text{parallel}} = \pi D L_p$$

$$\theta = \frac{C * W}{S_{\text{parallel}}}$$

$$\theta_c \leq 40^\circ$$

$$C = \frac{0.012}{1 + .1V_c}$$

$$V_c \uparrow \therefore \theta_c \downarrow$$



Brush	armature
$\delta = 6 \text{ A/cm}^2$	$\delta = 4.5 \text{ A/cm}^2$

$$P_{\text{Comm. surface}} = 3000 + 3165 = 6165 \text{ W}$$

$$S_{\text{Comm.}} = \pi D_c l_c = \pi * 1 * 0.4 = 1.256 \text{ m}^2$$

$$C = \frac{0.012}{1 + 0.1V_c} = \frac{0.012}{1 + 0.1 * 15.7} = 4.67 * 10^{-3} \text{ m}^2 \cdot ^\circ\text{C/W}$$

$$\theta_c = C \frac{P_{\text{Comm.}}}{S_{\text{Comm.}}} = 4.67 * 10^{-3} * \frac{6165}{1.256}$$

$$= 22.9^\circ\text{C} < 40^\circ\text{C}$$

$\therefore$ within limits. #

Interpole turns

1- For straight line commutation

$$T_c (\text{commutation time}) = \frac{t_b}{V_c} = \frac{\text{No of segments covered by brush}}{\text{no of segment} * n(\text{rps})}$$

$$e_{\text{reactance}} = L \frac{2I_a}{T_c}$$

2- For curved line commutation

W_c : commutator segment width

$$T_c = \frac{W_c}{V_c}$$

$$A_c = W_c * L_{\text{inter}}$$

$$B_{g_{\text{inter}}} = \phi_c * A_c$$

$$e_{\text{react}_{\text{inter}}} = 2N_{\text{c}_{\text{turn/coil}}} * B_{g_{\text{inter}}} L_{\text{inter}} V_c$$

Ampere Turn for interpole

$$AT_{\text{inter}} = AT_g + AT_{\text{iron}} + AT_{\text{armature}}$$

$$AT_g = 800000 * B_{g_{\text{inter}}} * K_{g_{\text{inter}}} * L_{g_{\text{inter}}}$$

$K_{g_{\text{inter}}}$: gap contraction factor

AT_{armature}	
Without compensating	With compensating
$AT_{\text{armature}} = \frac{I_c * Z}{2(2P)}$	$AT_{\text{armature}} = I_c * \frac{I_c * Z}{2(2P)} * (1 - \alpha)$

AT_{iron} from a condition in the problem

$$\text{commutating flux } \phi = B_{g_i} * w_c * l_i$$

Compensating winding

1- Select winding type

$$2- I_c = \frac{I_a}{2}$$

$$3- AT_a = Z * \frac{I_c}{2(2P)}$$

$$4- AT_{\text{comp}} = N_{\text{comp}} * I_a = \alpha * AT_a$$

$$Z_{\text{comp}} = 2 * N_{\text{comp}}$$

Checks and ranges

1- Slot Pitch and no of slot (τ_s & S)

Number of Slots :

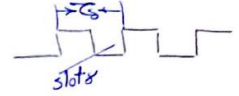
$$\tau_s = \frac{\pi D}{S}$$

$$2.5 \leq \tau_s < 3.5 \text{ cm}$$

$$\therefore \frac{\pi D}{2.5} > S > \frac{\pi D}{3.5}$$

$$I_c Z_c \leq 1500$$

$$I_c \frac{Z}{S} \leq 1500$$



$$S \geq \frac{I_c Z}{1500}$$

$$9 < \frac{S}{2P} < 16$$

$$9 * 2P < S < 16 * 2P$$

$$S \leq 100, \quad 10 < S < 50$$

$$11 < S < 60$$

$$11 < S < 50$$

$$\text{افراد رقم} < S < \text{افراد رقم}$$

2- No of poles and pole pitch (τ_p & P)

$$P = \frac{60 * f}{n}$$

$$25 < f < 30$$

$$\tau_{PMax} = \frac{11000}{0.5 * ac}$$

3- No of coil side per slot (U)

$$U = \frac{2C}{S}$$

$$\frac{E}{C} \geq V_{c.s}(12), C \geq \frac{E * 2a}{12}$$

$$C = U * \frac{S}{2} \quad \text{condition } \frac{Z_s}{U} = 1 \text{ or integer}$$

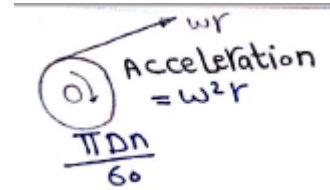
No of turns per coil

$$T_c = \frac{Z}{2 * C}$$

4- Linear velocity (V_a)

$$V_a = \frac{\pi D n}{60}$$

$$15 < V_a < 30 \text{ m/s}$$



5- No of conductor

$$Z = \frac{E_a * 2a}{BLv_a} = \frac{\pi D A_c}{I_c}$$

Conductors per slot

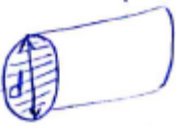
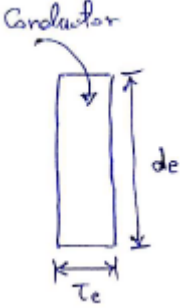
$$Z_s = \frac{Z}{S} \text{ (must be even number)}$$

6- Dimension of conductor (A_c)

$$4.5 \leq d_e \leq 7 \text{ A/mm}^2$$

$$I_c = \frac{I_a}{2a}$$

$$A_c = \frac{I_c}{d_e}$$

<u>$a_c < 9\text{mm}^2$</u>	<u>$a_c > 9\text{mm}^2$</u>
$a_c = \frac{\pi d^2}{4}$ 	$a_c = t_e * d_e$ $3t_e < d_e < 5t_e$ 

7- Types of winding

wave	Lap
$2a = 2$ $I_c < 250 A$	$2a = 2p$

8- Connection of winding

Progressive	Retrogressive
$y_{commutator} = +1$ $y_B \text{ (back pitch)} = \frac{C}{P} + 1$ $y_f \text{ (forward pitch)} = \frac{C}{P} - 1$	$y_{commutator} = -1$ $y_B \text{ (back pitch)} = \frac{C}{P} - 1$ $y_f \text{ (forward pitch)} = \frac{C}{P} + 1$

9- Pole pitch and ampere current

$$\tau_p = \frac{\pi D}{2P}$$

$$ac = \frac{Z * I_c}{\pi D}$$

Proofs

1- Ampere Turn per unit

$$\frac{AT}{h_e} = \frac{N_F I_F}{h_e} = \frac{N_F (af * d_e)}{h_e} = \frac{d_e h_e b F_e}{h_e} = \sqrt{\frac{2P_e}{\rho b F_e}} * b F_e = \sqrt{\frac{2P_e b F_e}{\rho}}$$

2- Power of armature

$$P = E_a I_a * 10^{-3} \text{ Kw} = \left(\frac{2P}{2a} \phi Z \frac{n}{60} \right) (I_c * 2a) * 10^{-3}$$

$$\frac{I_c Z}{\pi D} = \overline{ac}, I_c = \frac{I_a}{2a}$$

$$\therefore P_a = \frac{\pi^2}{60} * 10^{-3} D^2 L B * \frac{I_c Z}{\pi D} * n$$

$$P_a = -.164 * 10^{-3} D^2 L B * \overline{ac} * n = C_0 D^2 L B * ac$$

$$\therefore \frac{P_a}{n} = C_0 D^2 L$$

$$C_0 = 0.164 * 10^{-3} * B * ac \text{ (Power coefficient)}$$

3- Number of conductors

$$E_A = \frac{2P}{2a} * \phi * Z * \frac{n}{60}$$

$$E_a = B * L * V_a * \frac{Z}{2a}$$

$$Z = \frac{E_a * 2a}{BLV_a}$$

$$Z = \frac{I_c Z}{\pi D}$$

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$$R = \frac{V}{I} = \frac{\rho l_e N_F}{a_f} \text{ (Resistance of field)}$$

$$\therefore a_F = \frac{\rho l_e}{V} N_F I_F = \frac{\rho L_e N_F I_F}{R_F} = \frac{\rho L_e}{V} (AT)_F \quad (\text{area of field winding})$$

$$a_f = \frac{\pi}{4} d_i^2 \rightarrow d_i = \sqrt{\frac{4}{\pi} a_f}$$

$$d_o = d_i + 2t$$

$$F_e = \frac{a_f}{d_o^2}$$

$$d_e = \sqrt{\frac{2P_e}{\rho b F_e}} \quad (\text{Current density in field winding})$$

$$I_F = d_e * a_f = \sqrt{\frac{P_F}{R_F}} \quad (\text{Field Current})$$

$$\frac{AT}{h_e} = \sqrt{\left(\frac{2P_e b f_e}{\rho}\right)}$$

$$h_e = \frac{AT}{\left(\frac{AT}{h_e}\right)}$$

$$P_F = d_e^2 h_e l_e f_e \rho b = 2 h_e l_e P_e$$

$$I_{sh} = \frac{P_F}{V} = 2 \frac{h_e l_e P_e}{V}$$

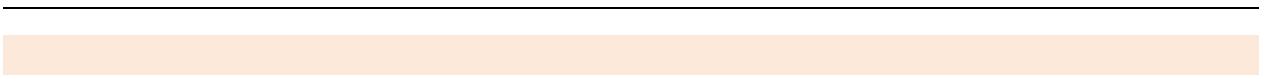
$$N_f = \frac{AT}{I_{sh}}$$

$$\text{No of Turns Per Layer} = \frac{h_e}{d_o}$$

$$\text{No of Layers} = \frac{\text{No of Turns}}{\text{No of Turns Per Layer}}$$

$$N_{f(new)} = \text{No of Turns per layer} * \text{No of Layers}$$

$$b(new) = \text{No of layers} * d_o$$



To design any motor we know the (Power – Voltage – Speed) required

$$E_A = K' \phi n \Rightarrow K' = \frac{2P * Z}{2a * 60}$$

$$\phi = BA = B \tau_p L = B \left(\frac{\pi D}{2P} \right) L$$

$$\therefore E_A = \frac{2P}{2a} \phi Z \frac{n}{60} = \frac{Z}{2a * 60} B (\pi D) L n$$

Some constants :

$$\alpha = \frac{\text{Pole arc}}{\text{Pole Pitch}} = (0.65 \rightarrow 0.7)$$

$$\beta = \frac{\text{axial lenght}}{\text{pole arc}}$$

$$\alpha\beta = \frac{\text{axial lenght}}{\text{pole pitch}} = \frac{K}{\tau_p} = \frac{2PL}{\pi D}$$

Choice of 2P

$$I_c < 250 \text{ A}$$

$$f = \frac{Pn}{60} \quad 25 < f < 30 \text{ Hz}$$

the least no of parallel paths is 2

$$\tau_p = \frac{\pi D}{2P} : \tau_{p_{Max}} = \frac{11000}{0.5 \overline{ac}} \rightarrow \frac{(\overline{ac}) * \tau_p}{2} = 11000$$

if $\tau_b > \tau_{b_{Max}}$ $P \uparrow$ or $D \downarrow$

$$V_a = \frac{\pi D}{60} n \quad . V_a \leq 15 : 30 \text{ m/s}$$

$$V_{\text{between adjacent segments}} < 15 \text{ V (simplex lap)} : 20 \text{ V}$$

$$\text{Min no of conductors} : \frac{E * 2P}{15}$$

$$E = Blv_a \frac{Z}{60} \rightarrow Z = \frac{E * 2a}{Blv}$$

$$ac = \frac{I_c Z}{\pi D} \rightarrow Z = \frac{\pi D * ac}{I_c}$$

$$emf_{conductor} = BLV_a$$

Dimension of armature conductor

$$A_a = \frac{I_c}{\delta}$$

Factors that determine the number of slots

- 1- Slot pitch τ_s
- 2- Equalizing connectors $\frac{S}{2P}$
- 3- $\frac{S}{2P}$ range from 9 to 16
- 4- Slots per pole arc $= \alpha \frac{S}{2P}$ (integer + 0.5) to reduce flux pulsation



$$b_1 = \alpha \tau_p$$

- 5- ac/slot
- 6- No of coil side per slot $Z_s = \frac{Z}{S} = 1(\text{Min})$ or even number
- 7- Max Voltage between two adjacent segments

$$A_a = \frac{I_c}{\delta} > 9mm$$

$$rectangulatr : A_c = c_d c_b \quad \text{ot Circle} : A_c = \frac{\pi d_c^2}{4}$$

No of coils

$$u = \text{No of coil side per slot}, u = \frac{2C}{S}$$

$$\Rightarrow C = \frac{uS}{2}$$

$$\frac{E_a}{\frac{C}{2a}} \leq 12 \rightarrow \text{condition}$$

$$C (\text{miniumum no of coils}) \geq \frac{E_a * 2a}{12}$$

$$\text{No of turn per coil } T_c = \frac{Z}{2C}$$

$$\phi_{new} = \alpha * B_{g_{new}} \tau_p L = B_{g_{new}} \tau_p L$$

$$B L_i = \frac{\phi_{new}}{b_p}$$

$$L_i = \frac{\phi_{new}}{K_f \left(\frac{S}{2P} \right) b_{teff} B_{app}}$$

$$\frac{L_i}{L} = \text{stacking factor} = 0.9$$

$$L = \frac{L_i}{0.9} + n_v L_v$$

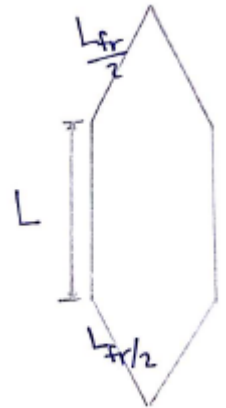
Resistace of Armature

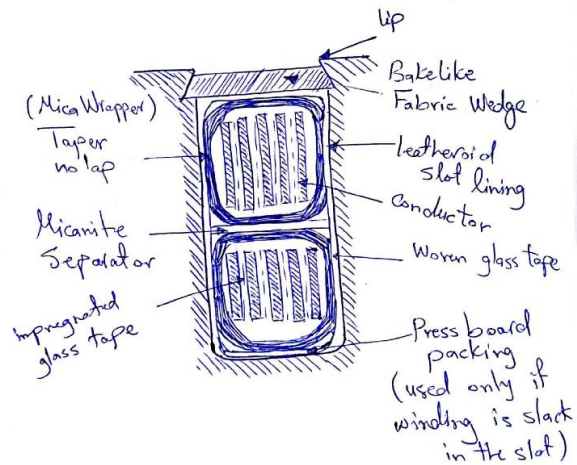
$$L_a = \text{conductor lenght} + \text{over hang lenght}$$

$$L_a = L_a + 2 \left(\frac{L_{fr}}{2} \right)$$

$$R = \frac{\rho L_a}{A_c}$$

$$R_t = \frac{\rho L_a}{A_c} * Z$$





$$Y_{eq} = \frac{\text{no. of coils}}{\text{no. of pair of poles}} = \frac{C}{P} = \frac{360}{3} = 120 \quad (9)$$

$$\begin{aligned} \text{No. of tappings} &= \text{no. of rings} \times \text{no. of pair of poles} \\ &= 10 \times 3 \\ &= 30 \end{aligned}$$

$$Y_{ph} = \frac{\text{no. of coils}}{\text{no. of rings} \times \text{no. of pair of poles}} = \frac{360}{10 \times 3} = 12$$

Equalizer ring table:

Ring no.	1	2	3	4	5	6	7	8	9	10
Connected to	1	13	25	37	49	61	73	85	97	109
Coil	121	133	145	157	169	181	193	205	217	229
no. :	241	253	265	277	289	301	313	325	337	349